



# EVALUATION PROGRAM for SECONDARY SPACECRAFT CELLS

SYNCHRONOUS ORBIT TESTING  
OF  
6.0 AMPERE-HOUR SEALED NICKEL-CADMIUM CELLS  
MANUFACTURED BY  
GENERAL ELECTRIC COMPANY

prepared for  
GODDARD SPACE FLIGHT CENTER  
CONTRACT S-23404-G

QUALITY EVALUATION AND ENGINEERING LABORATORY  
NAD CRANE, INDIANA

NASA-CR-136317) EVALUATION PROGRAM FOR  
SECONDARY SPACECRAFT CELLS: SYNCHRONOUS  
ORBIT TESTING OF GENERAL ELECTRIC COMPANY  
6.0 AMPERE-HOUR SEALED (Naval Ammunition  
Depot) -  
47 P HC \$4.50  
48

Unclassified  
25314

N74-13762

**DEPARTMENT OF THE NAVY  
NAVAL AMMUNITION DEPOT  
CRANE, INDIANA 47522**

IN REPLY REFER TO:  
3053-DEC:wh  
8900  
4 DEC 1973

From: Commanding Officer, Naval Ammunition Depot, Crane, Indiana  
To: National Aeronautics and Space Administration, Goddard Space Flight Center (761, Mr. T. J. Hennigan), Greenbelt, Maryland 20771

Subj: Report QEEL/C 73-302; Evaluation program for secondary spacecraft cells; synchronous orbit testing of 6.0 ampere-hour sealed nickel-cadmium cells manufactured by General Electric Company

Ref: (a) NASA Purchase Order S-23404-G

Encl: (1) Report QEEL/C 73-302

1. In compliance with reference (a), enclosure (1) is forwarded for information and retention.

*D. G. Miley*  
D. G. MILEY  
By direction

Copy to:  
Distribution List

I

DEPARTMENT OF THE NAVY  
NAVAL AMMUNITION DEPOT  
QUALITY EVALUATION AND ENGINEERING LABORATORY DEPARTMENT  
CRANE, INDIANA 47522

EVALUATION PROGRAM  
FOR  
SECONDARY SPACECRAFT CELLS

SYNCHRONOUS ORBIT TESTING  
OF  
GENERAL ELECTRIC COMPANY  
6.0 AMPERE-HOUR SEALED NICKEL-CADMIUM CELLS

QEEL/C 73-302

15 October 1973

PREPARED BY:

D. E. Christy  
D. E. CHRISTY

PREPARED UNDER THE DIRECTION OF:

D. E. MAINS  
D. E. MAINS, Manager  
Space Satellite Cell Program Branch

APPROVED:

J. G. Miley  
D. G. MILEY  
By direction

II

Enclosure (1)

REPORT BRIEF

RESULTS OF SYNCHRONOUS ORBIT TESTING

OF

6.0 AMPERE-HOUR SEALED NICKEL-CADMIUM CELLS  
MANUFACTURED BY  
GENERAL ELECTRIC COMPANY

- Ref: (a) NASA Purchase Order S-23404-G  
(b) NASA 1tr BRA/VBK/pad of 25 Sep 1961 w/BUWEPS first end  
FQ-1:WSK of 2 Oct 1961 to NAD Crane  
(c) NASA Work Sheet of Apr 1967

I. TEST ASSIGNMENT BRIEF

A. In compliance with references (a) and (b), evaluation of sealed nickel-cadmium cells was begun according to the program outlines of reference (c).

B. The purpose of this evaluation is to gather performance information concerning sealed nickel-cadmium cells operating under a synchronous orbit regime. Such a regime simulates a space satellite maintaining a position over a fixed point on earth as the earth rotates on its axis and revolves about the sun.

C. This report is a continuation of NAD Crane report QE/C 70-634 which covers the first three years of tests.

II. SUMMARY OF RESULTS

A. A temperature of 40°C is very detrimental to cells in a synchronous orbit regime as may be noted from the low capacities for the 40°C pack.

B. A temperature of -20°C results in high cell voltages during charge, and an extremely low trickle charge (C/240) must be maintained to keep the voltage at or near 1.50 volts.

C. Coulometers are effective charge control devices (particularly at -20°C) when operative. However, they have shorter lives than the cells they control.

D. The voltage balance, during discharge, between the high and low cells of a synchronous pack is best at 25°C and worst at 40°C. Also, age and greater depths of discharge result in greater degradation of pack voltage balance.

E. All packs, except 5 and 6 which are coulometer controlled, show a tendency to be reconditioned by the capacity check at the middle of each eclipse. Thus, with a constant discharge current but increasing cell voltage, the data indicates a slight increase in the cell's capability to deliver power during the last half of each eclipse season following a capacity check.

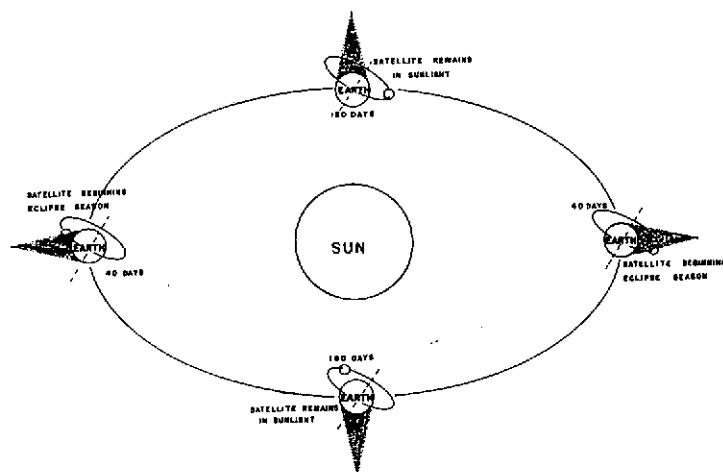
RESULTS OF  
 CONTINUOUS SYNCHRONOUS ORBIT TESTING  
 ON  
 6.0 AMPERE-HOUR SEALED NICKEL-CADMIUM CELLS  
 MANUFACTURED BY  
 GENERAL ELECTRIC COMPANY

### I. INTRODUCTION

A. The synchronous orbit tests were begun on six, 5-cell packs on 18 July 1967. They have completed ten eclipses and continue to cycle with one exception. Pack 4 failed on 6 February 1968 and was replaced by pack 4B (with a coulometer) on 2 August 1968. Pack 4B has completed eight eclipses.

B. A separate report (QE/C 71-183) covers synchronous orbit testing on auxiliary electrode cells.

C. In a synchronous orbit, the velocity of a satellite and its distance from the earth are adjusted such that one revolution of the satellite matches one rotation of the earth. Such a satellite remains fixed over one location on the earth. The earth's shadow cone changes relative to the satellite's plane of orbit. (See diagram.) Thus, every 180 days the satellite enters an eclipse season. This season lasts approximately 40 days after which the remaining 140 days are in continuous sunlight. At the beginning of an eclipse season, the satellite first moves through the outer area of the earth's shadow cone. Each day of the eclipse season it progresses through a different section of the shadow cone until it has completely traversed the cone at the end of the season. The satellite's time within the shadow cone thus varies from day to day within the eclipse season beginning with a minimum, progressing to a maximum, and returning to a minimum.



## II. TEST CONDITIONS

A. To simulate the conditions experienced by the space cells aboard a synchronous orbiting satellite, the following 182-day test regime was adopted.

### 1. Period simulating continuous sunlight (140 days):

a. The cells were continuously charged at 200 milliamperes except the cells in pack 4B whose coulometer limited them to 25 milliamperes.

### 2. Period simulating eclipse season (42 days):

a. All cells were discharged for 12 minutes the first day of the eclipse season. The discharge time increased by 3 to 4 minutes per day for 18 days to a maximum of 1 hour and 12 minutes. This maximum discharge then occurs once a day for 8 days (18th through 25th day of eclipse season) with one exception--a capacity check was always run during the middle of each eclipse season.

b. The capacity check was run on the 21st day of the eclipse season. The capacity check consisted of a constant current discharge (rate depending on the depth of discharge) to an average voltage of 1.00 volt per cell or 0.50 volt on the low cell, whichever came first. This differed from the other daily discharges during an eclipse only in that the low cell was then allowed to go as low as 0.00 volt before termination of the discharge.

c. Following the capacity check, the cells continued the daily discharge of 1 hour and 12 minutes through the 25th day of the season. From the 26th day to the end of the season, the discharge was shortened 3 to 4 minutes per day. The last day's discharge was 12 minutes, the same as the first day. The cells then returned to continuous charge (sunlight) completing the 180-day cycle.

B. The following table identifies the synchronous packs and gives the test parameters of each pack plus changes or cell removals having occurred following the sixth eclipse to the tenth for all but pack 4B. Pack 4B covers the period following eclipse four to the eighth eclipse.

TABLE I

Pack No.	Temp °C	Depth of Discharge	Charge Rate (ma)	Discharge Rate (amps)	Charge Control	Day	- ECL -	Change or Removal Reason
1	40	40	200	2.0	None**	1291	7 Sun 8	Analysis C-5
2	25	40	200	2.0	None**	1291	7 Sun 8	Analysis C-5
3	0	40	200	2.0	None**	1291	7 Sun 8	Analysis C-1
4	-20	40	200	2.0	None**	200	- 1 -	Removed 2-6-68 Cell 2 reverse
4B	-20	40	200*	2.0	Coulometer	1089	- 7 -	CLM Replaced
5	0	60	300*	3.0	Coulometer	1291	7 Sun 8	Analysis C-5
6	0	80	400*	4.0	Coulometer	1161	7 Sun 8	Failure Analysis C-4

\*The cells are charged at specified rates until limited by their respective coulometers to 25 milliamperes (4B) or 200 milliamperes (5 and 6).

\*\*The charge currents are controlled by regulated power supplies.

### III. CELL DESCRIPTION

A. The cells are nickel-cadmium, 6.0 ampere-hour, manufactured by General Electric. They are rectangular and hermetically sealed with stainless steel containers and covers. The separator material is pellon. The terminals are insulated from the cell cover by ceramic seals, and the terminals protrude through the cover with solder tabs welded to the top.

### IV. TEST RESULTS

A. The results of this report are a continuation of NAD Crane Report QE/C 71-183 which covers the first three years of tests.

B. The test results of the eclipse seasons are shown graphically in Figures 1 to 18. The three graphs pertaining to each synchronous pack follows the discussion of each pack. Each three-graph group shows: (1) end-of-charge (eoc) voltage; high cell \*\*\*, average +++, low cell ..., and coulometer voltage (if applicable) xxx, (2) end-of-discharge (eod) voltage; high cell \*\*\*, average +++, low cell ..., and coulometer (if applicable) xxx, and (3) ampere-hours in +++ and out \*\*\*. The format did not allow all points of the successive eclipses to be plotted. Thus, the following table shows the day of the eclipse corresponding to the position recorded.

<u>Pos</u>	<u>Day</u>	<u>Pos</u>	<u>Day</u>
1	1	15	22
2	3	16	23
3	5	17	24
4	7	18	25
5	9	19	26
6	11	20	27
7	13	21	28
8	14	22	29
9	15	23	31
10	16	24	33
11	17	25	35
12	18	26	37
13	19	27	39
14	20	28	42

Example: Sync 1, 2, 3, 5 and 6 all begin eclipse 7 with day 1110. If all 42 days of the eclipse season were plotted, the days would be 1110, 1111, 1112, 1113, 1114...Instead the points plotted correspond to days 1110, 1112, 1114, 1116, 1118.

1. Sync 1: The successive eclipse seasons (7 through 10) for this pack are shown in Figures 1 to 3.

a. End-of-Charge (eoc) Voltage (Figure 1): The voltage of the high cell during each eclipse is a maximum the fifth day of each eclipse except for eclipse 10--maximum after 11 days. Also this maximum voltage descends from 1.50 volts to 1.42 volts in very nearly a linear manner. Secondly the difference, in voltage, between the high and low cell diminishes after the 5th day. Thirdly, the average voltage plateau near the time corresponding to the capacity check (period of maximum discharge), and this voltage plateau increases in eclipses 7 through 9 and remains at the same level in eclipse 10. The levels increase as follows: eclipse 7, 1.382 volts; eclipse 8, 1.392 volts; eclipse 9, 1.396 volts; eclipse 10, 1.396 to 1.398 volts. This latter eclipse shows no real pattern to its overall voltage--mainly scattered.

b. End-of-Discharge (eod) Voltage (Figure 2): During eclipse 7 the discharge voltage of the low cell went to 0.00 volts which terminated the discharge 6 minutes early. This is reflected in the average cell voltage plateauing at 0.60 volts for eclipse 7 which all the other eclipses showed an average voltage plateau of 0.72 or above.

c. Ampere-Hours In and Out (Figure 3): The ampere-hours out "tail-off" in each eclipse following the capacity. Also the maximum capacity out declines with each successive eclipse.

KEY  
 \* HIGH EOC  
 + AVE EOC  
 - LOW EOC  
 X COLU EOC

SYNCHRONOUS ORBIT SHADOW PLOT

PACK = 1

DEPTH DISCHARGE 40.0  
 TEMPERATURE 40.0 C  
 AMPERE RATE 6.00  
 CATALOG  
 SERIAL 04-32, 07-10, 07-11, 11-19, 11-26  
 GENERAL ELECTRIC CELLS  
 PROJECT ATS F+G

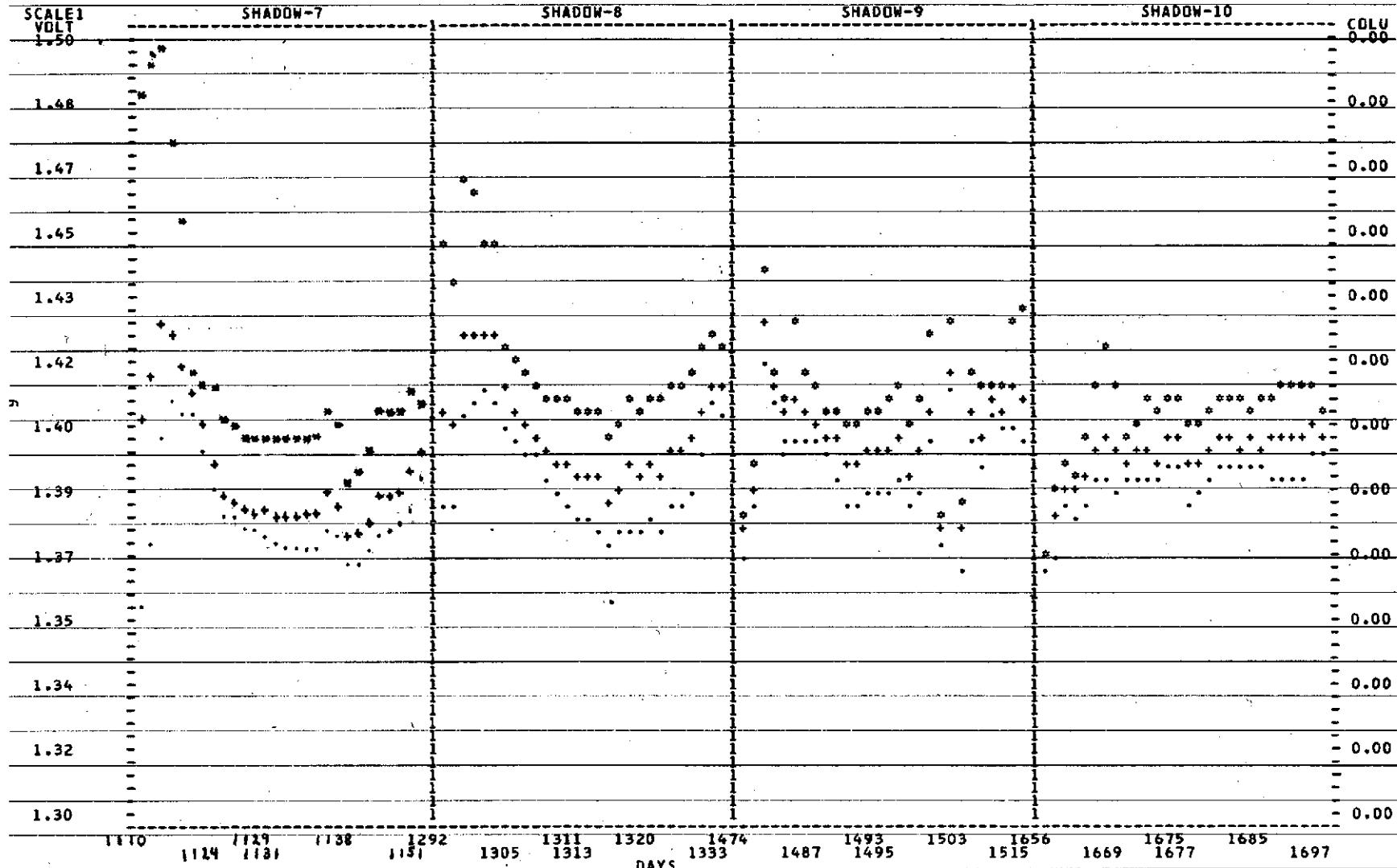


FIGURE 1



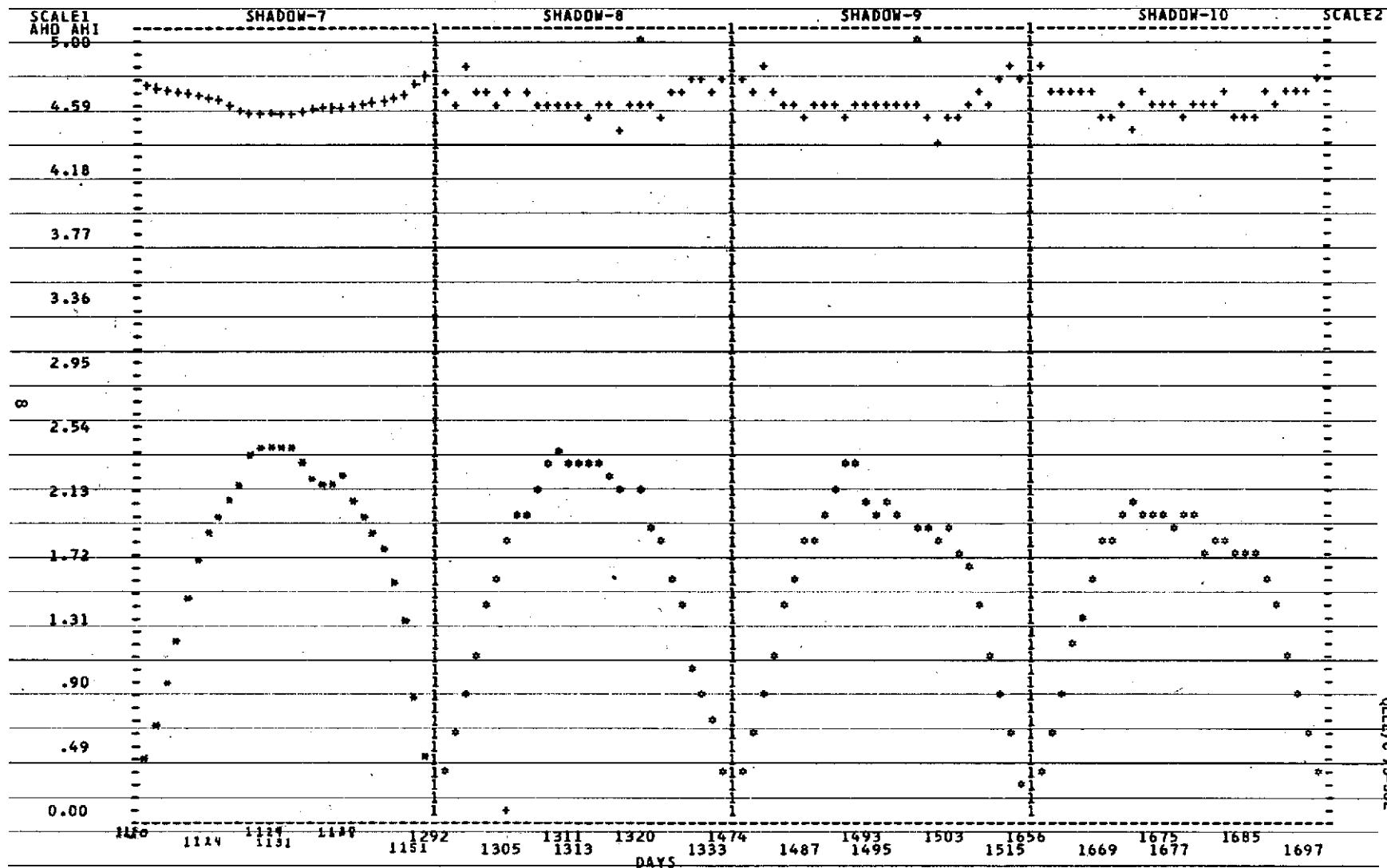
**KEY**

- ♦ AHO
- + AHI-TOTAL

## **SYNCHRONOUS ORBIT SHADOW PLOT**

PACK = 1

DEPTH DISCHARGE 40.0  
TEMPERATURE 40.0 C  
AMPERE RATE 6.00  
CATALOG  
SERIAL 04-32.07-10.0  
GENERAL ELECTRIC CELL  
PROJECT ATS F+G



QEE1/C  
73-302

FIGURE 3

2. Sync 2: The successive eclipse season (7 through 10) for this pack are shown in figures 4 to 6.

a. End-of-Charge Voltage (Figure 4): The most striking characteristic of these curves is the consistently wide divergence of the high and low cell voltage. This divergence diminishes after the 10th or 11th data point which corresponds to the 16th or 17th day of each successive eclipse season.

b. End-of-Discharge Voltage (Figure 5): The effects of the capacity check at the midpoint of each eclipse are very noticeable for this pack. Eclipses 7 and 8 show an increase in eod voltage following the capacity check. This trend is reversed in eclipses 9 and 10--in fact, the low cell has shown a dramatic drop in voltage from 1.17 (eclipse 8) to 1.08 volts (eclipse 10). Also of interest is the eod voltage the last day of each eclipse season. This showed a linear increase of roughly 0.01 volt for eclipses 7 through 9, with eclipse 10 dropping off the eod voltage of the last day.

c. Ampere-Hours In and Out (Figure 6): This set of curves illustrates expected behavior. Since no cells of the pack terminated discharge prematurely, the ampere-hours in and out are consistent.

KEY  
 \* HIGH EOC  
 + AVE EOC  
 LOW EOC  
 X COLU EOC

SYNCHRONOUS ORBIT SHADOW PLOT

PACK # 2

DEPTH DISCHARGE 40.0  
 TEMPERATURE -25. C  
 AMPERE RATE 6.00

CATALOG  
 SERIAL 04-41, 04-50, 06-21, 11-25, 11-3  
 GENERAL ELECTRIC CELLS  
 PROJECT ATS F+G

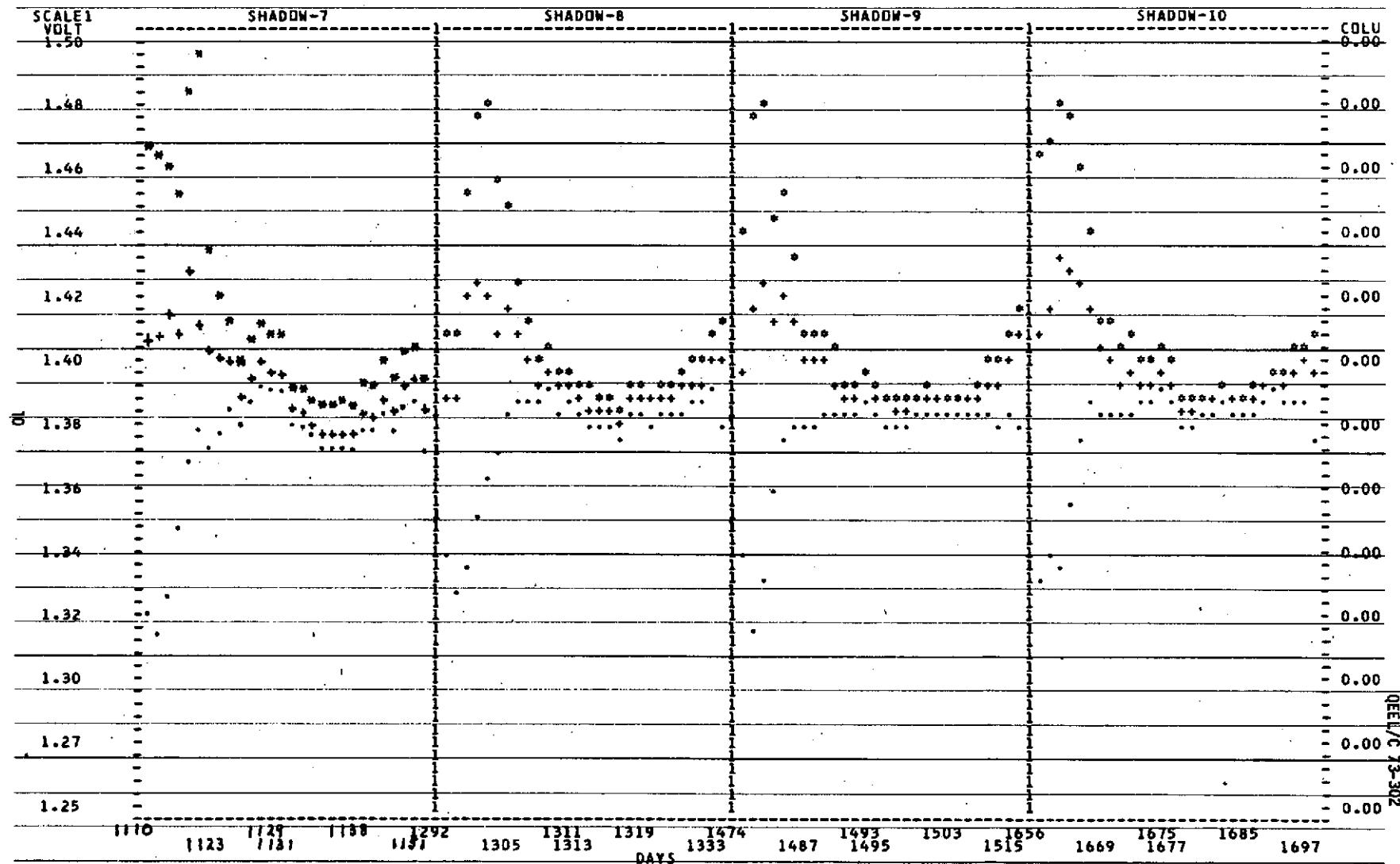


FIGURE 4

QEL/C 73-302

\* HIGH END DISCHARGE VOLTAGE  
 + AVE END DISCHARGE VOLTAGE  
 : LOW END DISCHARGE VOLTAGE  
 X COLD END OF DISCHARGE

### SYNCHRONOUS ORBIT SHADOW PLOT

PACK # 2

DEPTH DISCHARGE 40.0  
 TEMPERATURE -25. C  
 AMPERE RATE 6.00  
 CATALOG  
 SERIAL 04-41,04-50,06-21,11-25,11-3  
 GENERAL ELECTRIC CELLS  
 PROJECT ATS F+G

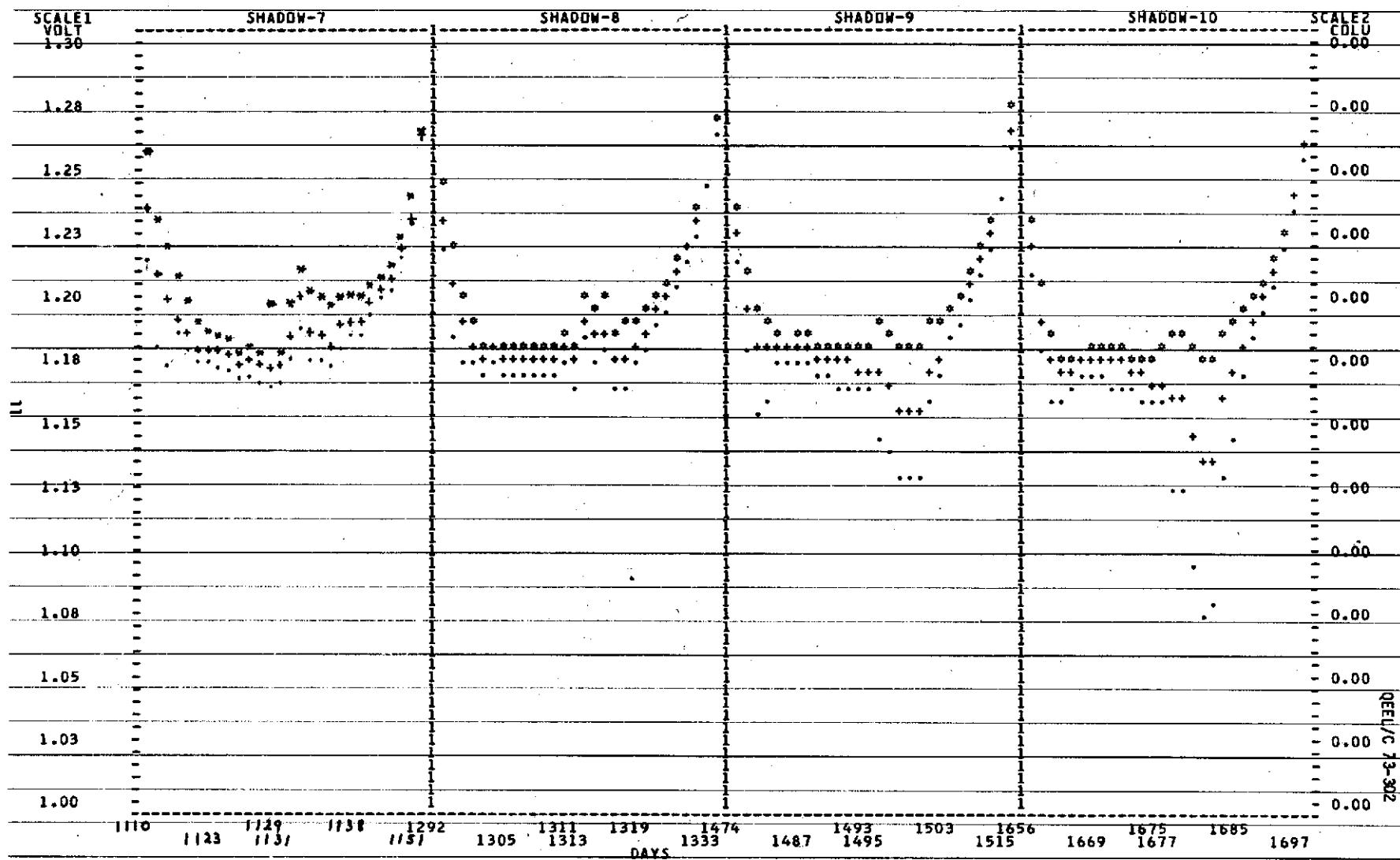


FIGURE 5

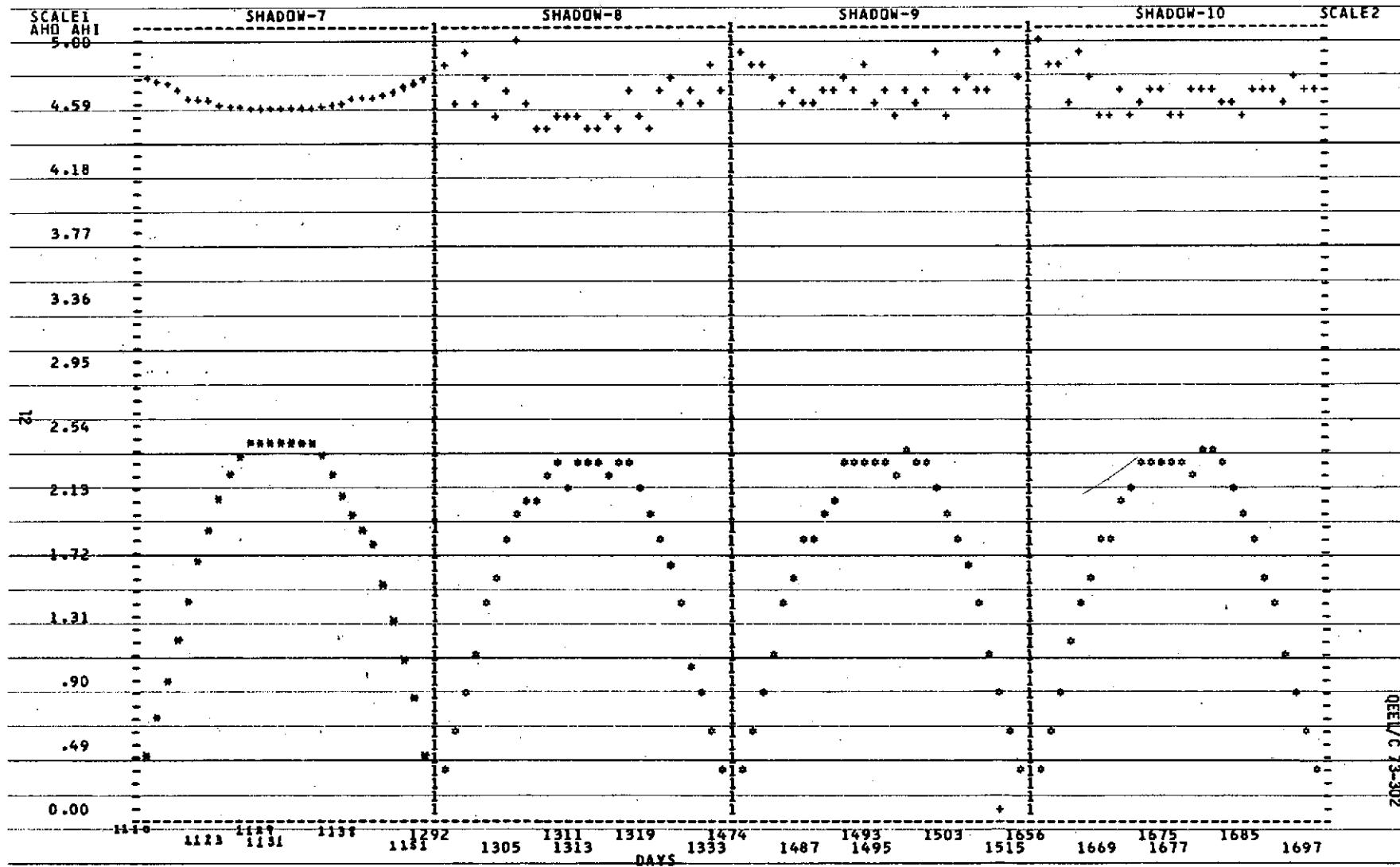
KEY  
 \* AHD  
 + AHI-TOTAL

SYNCHRONOUS ORBIT SHADOW PLOT

PACK # 2

DEPTH 40.0  
 DISCHARGE 40.0  
 TEMPERATURE -25. C  
 AMPERE RATE 6.00

CATALOG  
 SERIAL 06-4104-50, 06-21, 11-25, 11-3  
 GENERAL ELECTRIC CELLS  
 PROJECT ATS F+G



QEE/C 73-302

FIGURE 6

3. Sync 3: The successive eclipse seasons (7 through 10) for this pack are shown in figures 7 to 9.

a. End-of-Charge Voltage (Figure 7): The most significant factor to observe from this set of curves is found in shadow 9. During this shadow, several voltage points exhibit much wider fluctuation between high, average and low values. Differences of 1.00 volt between high and low cells may be noted.

b. End-of-Discharge (Figure 8): The average voltage of the first day vs. the last day of each eclipse season shows approximately a 0.02 volt increase in each shadow period. For eclipse 7 the low cell voltage shows a lower level than the rest of the eclipse seasons.

c. Ampere-Hours In and Out (Figure 9): No unusual characteristics are noted for this set of curves.

**KEY**

- \* HIGH EOC
- + AVE EOC
- LOW EOC
- X CDLU EOC

SYNCHRONOUS ORBIT SHADOW PLOT

PACK =

DEPTH DISCHARGE 40.0  
TEMPERATURE 0.0 C  
AMPERE RATE 6.00  
CATALOG  
SERIAL D4-39,06-08,06-23,11-34,11-36  
GENERAL ELECTRIC CELLS  
PROJECT ATS F+G

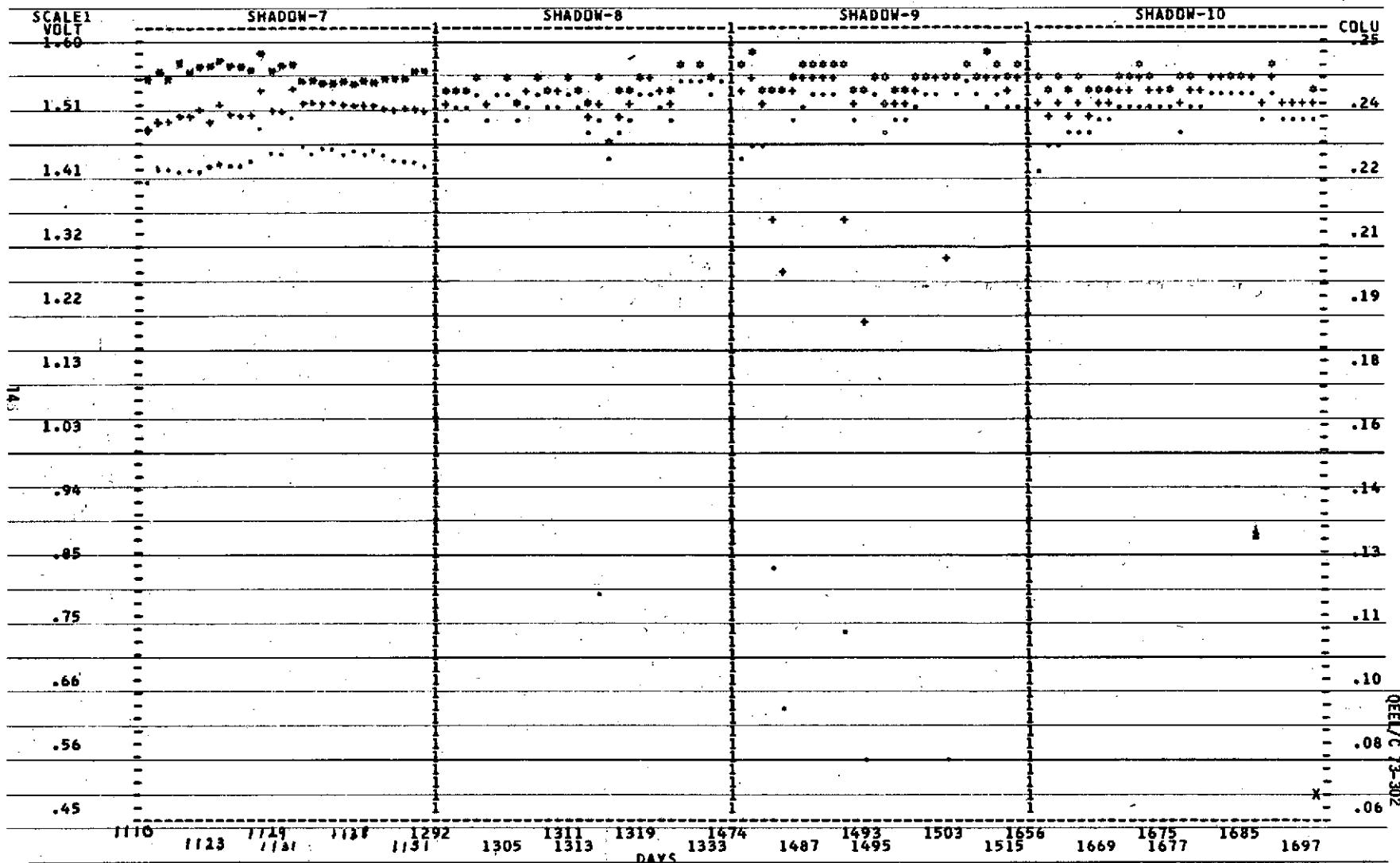


FIGURE 7

KEY

\* HIGH END DISCHARGE VOLTAGE  
+ AVE END DISCHARGE VOLTAGE  
X LOW END DISCHARGE VOLTAGE  
COLU END OF DISCHARGE

## **SYNCHRONOUS ORBIT SHADOW PLOT**

PACK = 2

DEPTH DISCHARGE 40.0  
TEMPERATURE 0.0 C  
AMPERE RATE 6.00  
CATALOG  
SERIAL 04-39,06-08,06-23,11-34,11-36  
GENERAL ELECTRIC CELLS  
PROJECT ATS F+G

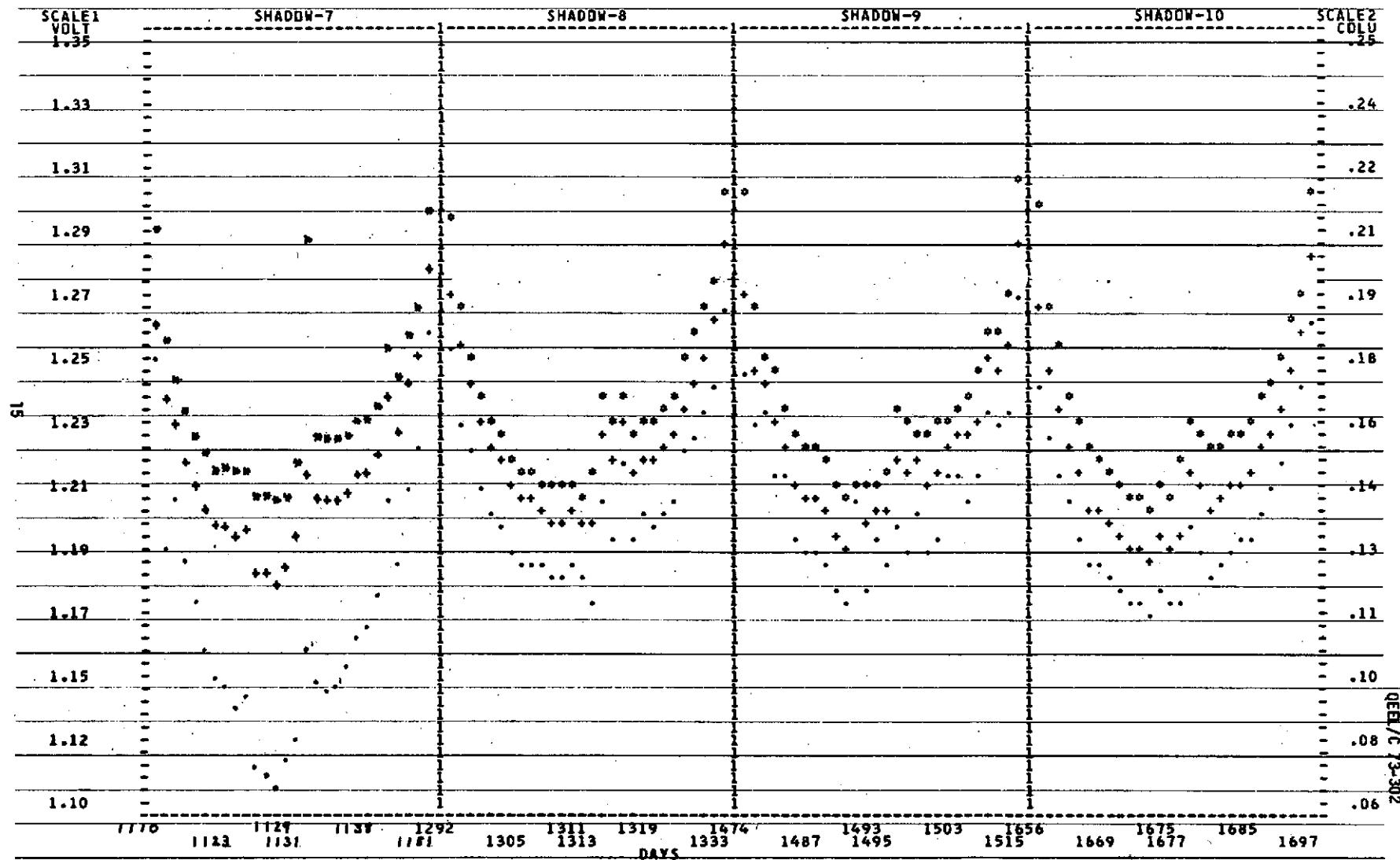


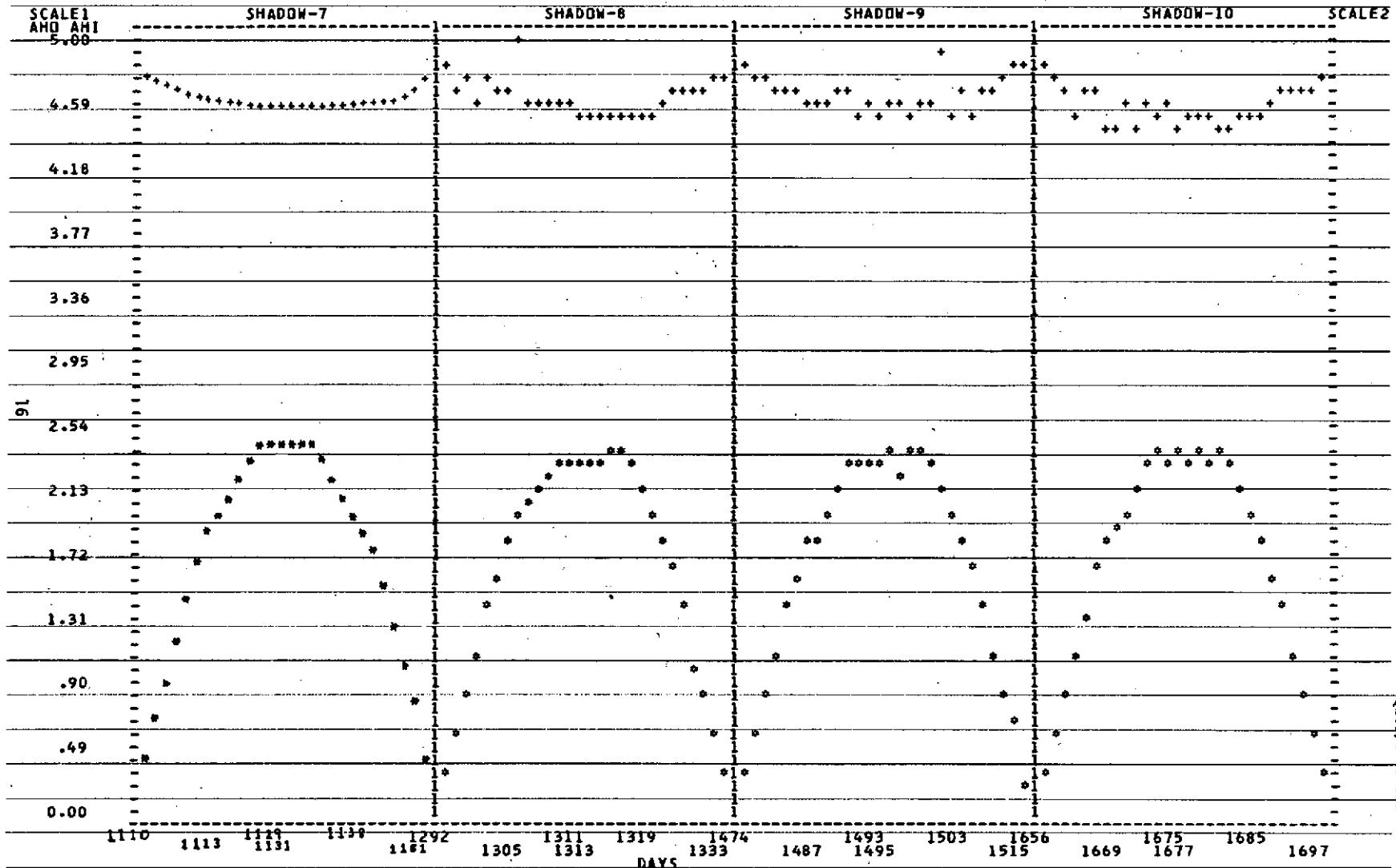
FIGURE 8

KEY

## SYNCHRONOUS ORBIT SHADOW PLOT

PACK 2

DEPTH DISCHARGE 40.0  
TEMPERATURE 0.0 C  
AMPERE RATE 6.00  
CATALOG  
SERIAL 04-39,06-08,06-23,11-34,11-36  
GENERAL ELECTRIC CELLS  
PROJECT ATS F+G



QEEL/C 73-302

**FIGURE 9**

4. Sync 4B: The successive eclipse seasons (5 through 8) for this pack are shown in figures 10 to 12.

a. End-of-Charge Voltage (Figure 10): The eoc voltage for this pack shows a much more sporadic behavior than the first three packs.

b. End-of-Discharge Voltage (Figure 11): The eod voltage for this pack shows sporadic behavior. There is no gradual voltage drop prior to the maximum period of discharge; there is no voltage plateau corresponding to the maximum discharge; nor is there a voltage rise following the maximum discharge. In short, none of the eclipses except number 8 shows any resemblance to the typical discharge curve. It is felt that the low operating temperature (-20°C) over a period of 4 years has accounted for this sporadic behavior.

c. Ampere-Hours In and Out (Figure 12): The only point out of line appears in eclipse 5 on the 751st day. This point corresponds to excessively high ampere-hours returned to the cell when compared to the other points. This was due to the charge current failing to trip to the lower level (.200A to .025A) until near the end of charge.

KEY  
 \* HIGH EOC  
 + AVE EOC  
 X LOW EOC  
 X COLU EOC

SYNCHRONOUS ORBIT SHADOW PLOT

PACK = 4B

DEPTH DISCHARGE 40.0  
 TEMPERATURE -20. C  
 AMPERE RATE 6.00  
 CATALOG  
 SERIAL 06-03-06 13.11-13.11-44.11-45  
 GENERAL ELECTRIC CELLS  
 PROJECT ATS F+G

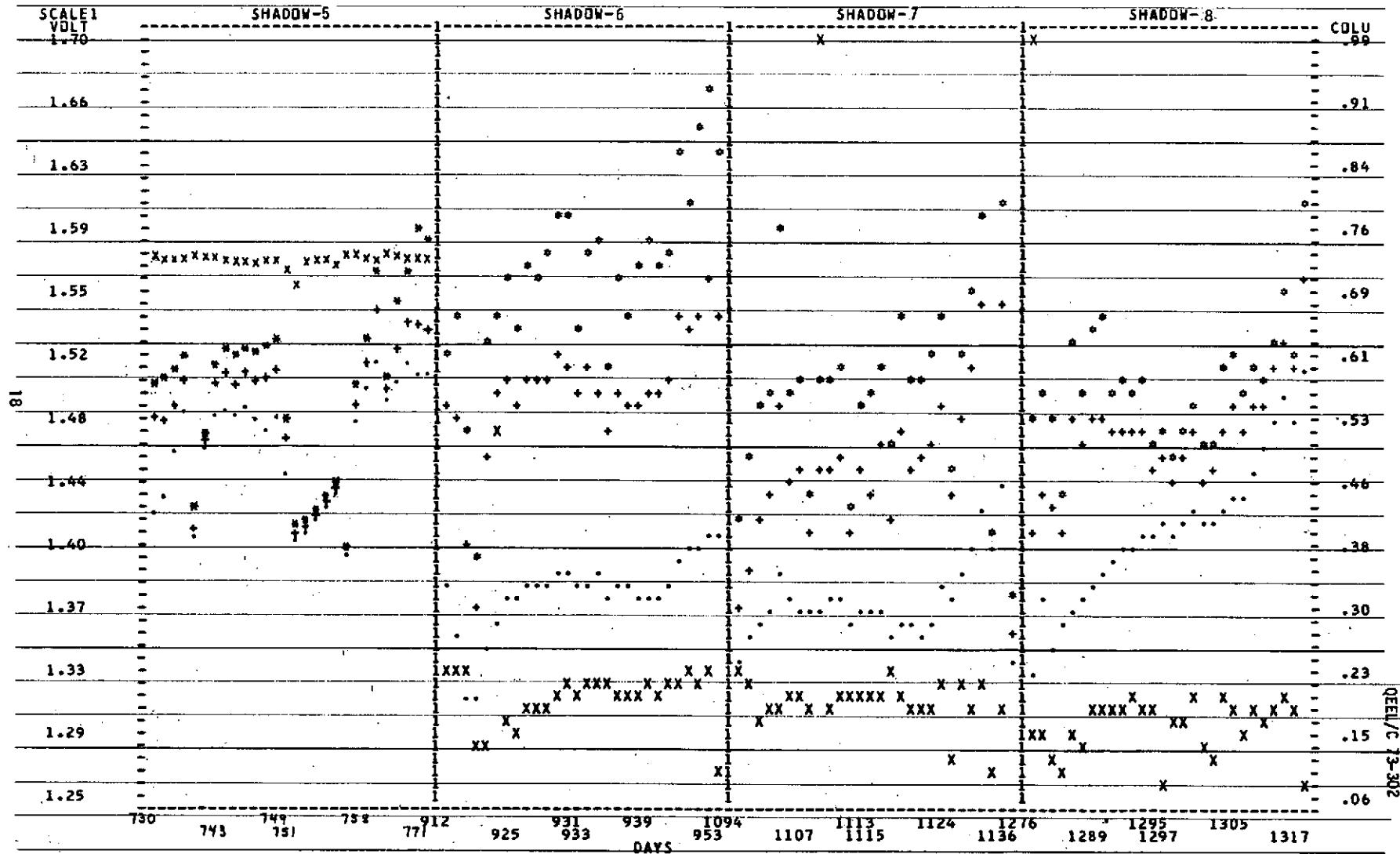


FIGURE 10

KEY

\* HIGH END DISCHARGE VOLTAGE  
+ AVE END DISCHARGE VOLTAGE  
X LOW END DISCHARGE VOLTAGE  
COLU END OF DISCHARGE

## SYNCHRONOUS ORBIT SHADOW PLOT

DEPTH DISCHARGE 40.0

TEMPERATURE -20.  
INFERE RATE 4.80

~~AMPERE RATE 6.00~~

**CATALOG  
SERIAL**

SERIAL  
GENERATOR

GENERAL  
PROJECT

PROJECT

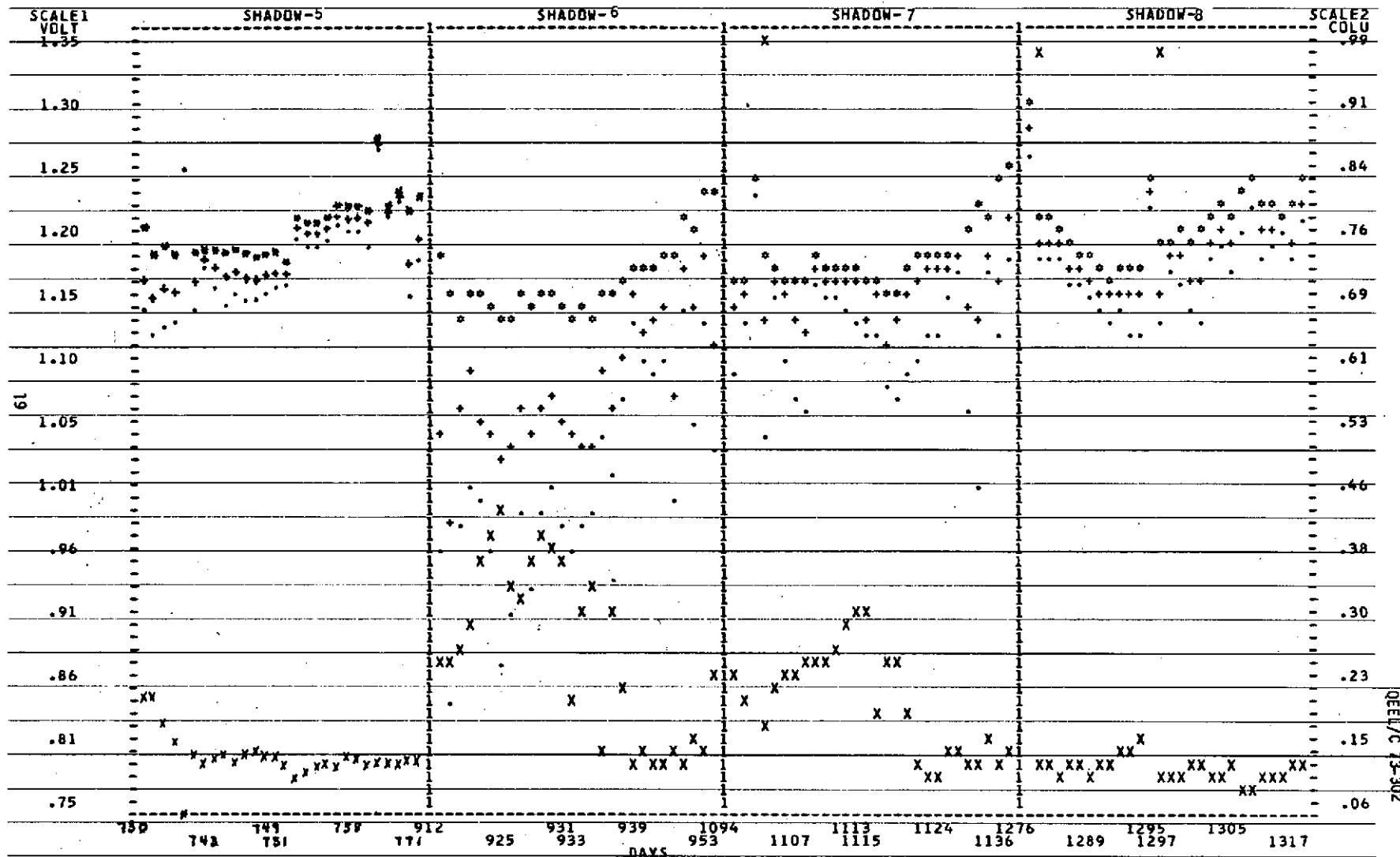
---

**SHADOW-8**

-----{-----}

1

PACK - 4



**FIGURE 11**

NCI  
+ AHO  
+ AHI-TOTAL

## SYNCHRONOUS ORBIT SHADOW PLOT

PACK = 4-B

DEPTH DISCHARGE 40.0  
TEMPERATURE -20. C  
AMPERE RATE 6.00  
CATALOG  
SERIAL 06-03-06-13.11-13.11-44.12-45  
GENERAL ELECTRIC CELLS  
PROJECT ATS F+G

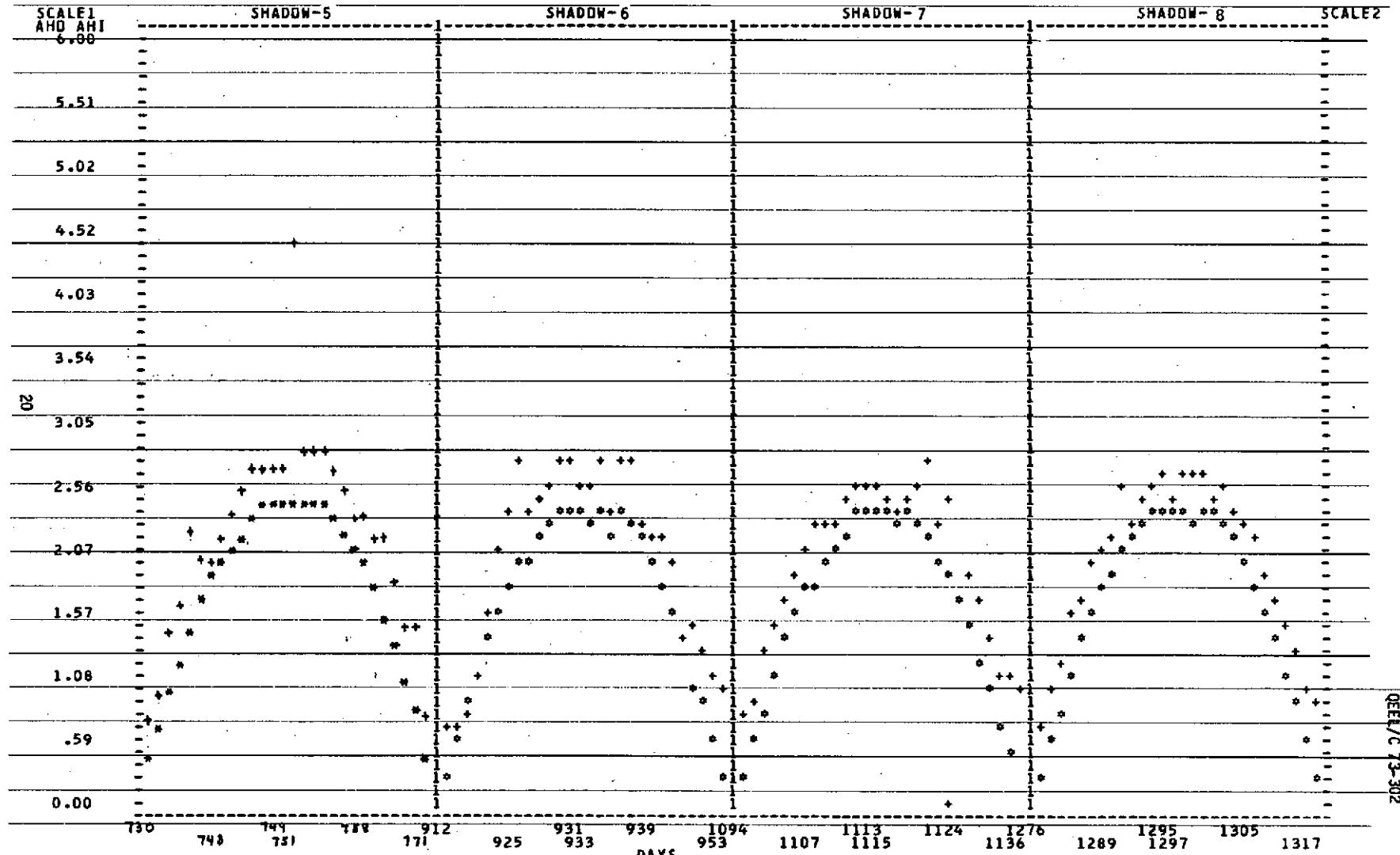


FIGURE 12

5. Sync 5: The successive eclipse seasons (7 through 10) for this pack are shown in Figures 13 to 15.

a. End-of-Charge (Figure 13): Historically, the eoc voltage for this pack has grown steadily more erratic--average voltage or otherwise. This trend continues, and is felt due to aging since eclipse 10 represents 5 years of testing.

b. End-of-Discharge (Figure 14): During eclipse 7 the low cell went below the voltage scale (0.895 volt, lowest) as may be verified from the graph. On 1 February 1971, during the float period between eclipses 7 and 8, this low cell was removed for analysis. Thus, eclipses 8 to 10 do not show a low cell going below 1.128 volts. Also the curves reveal more stability and less difference between the high and low cells as a result of the cell removal.

NOTE: The coulometer voltage for eclipse 7 was all negative and therefore not plotted because the data was off scale. The voltages ranged as follows: days 1110 to 1120 (-0.070 to -0.100 volt); day 1121 to 1141 (-0.070 to -1.696 volts); day 1142 to 1151 (-0.050 to -0.100 volt).

c. Ampere-Hours In and Out (Figure 15): No special significance is noted for this set of curves.

**KEY**

---

- \* HIGH EOC
- + AVE EOC

---

- LOW EOC
- X CULU EOC

## **SYNCHRONOUS ORBIT SHADOW PLOT**

PACK = 5

DEPTH DISCHARGE 60.0  
TEMPERATURE 0.0 C  
AMPERE RATE 6.00  
CATALOG  
SERIAL 11-43.11-42.1  
GENERAL ELECTRIC CEL  
PROJECT AT&T F+G

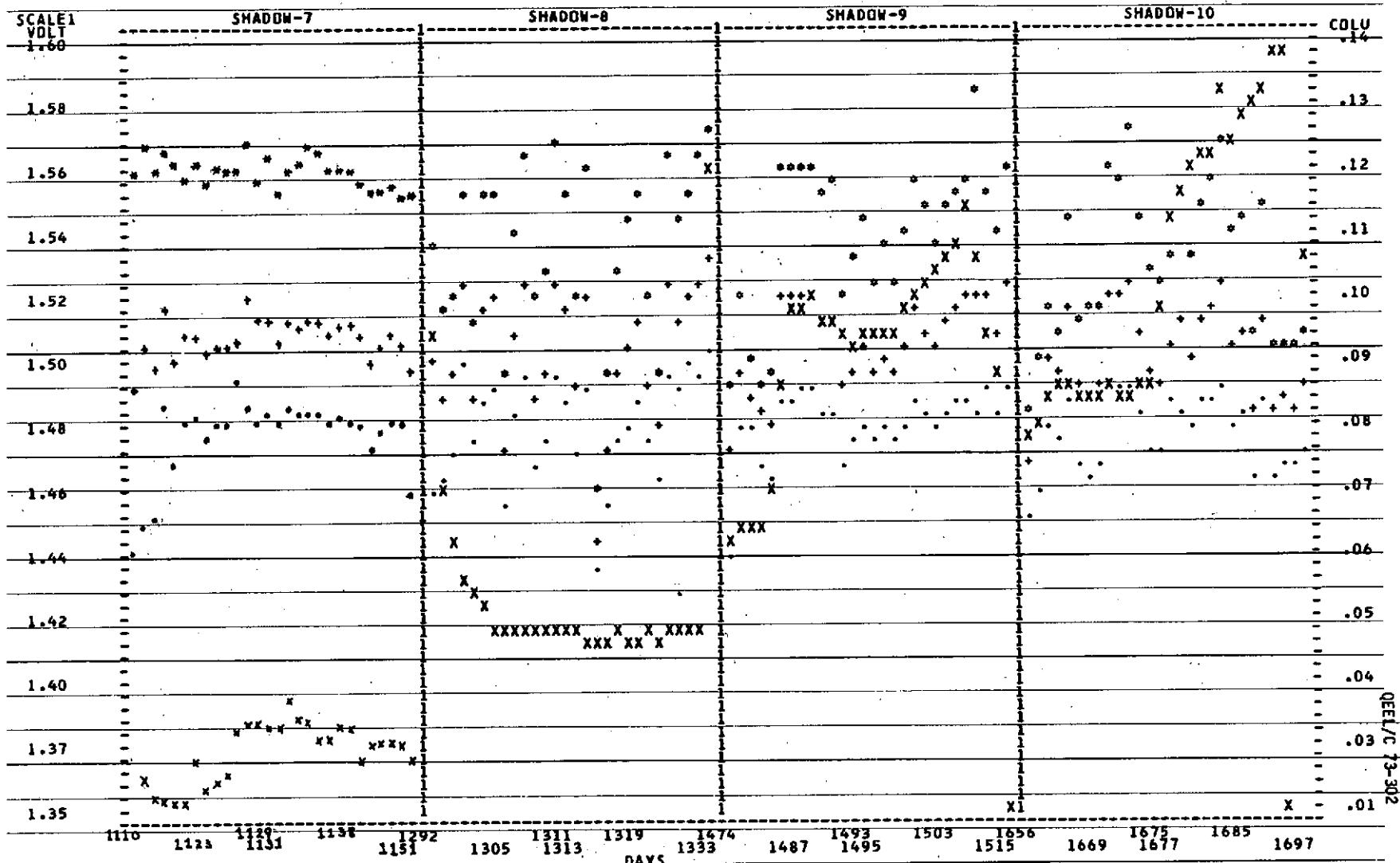


FIGURE 13

KEY  
 \* HIGH END DISCHARGE VOLTAGE  
 + AVE END DISCHARGE VOLTAGE  
 X LOW END DISCHARGE VOLTAGE  
 X COLU END OF DISCHARGE

SYNCHRONOUS ORBIT SHADOW PLOT

PACK # 5

DEPTH DISCHARGE 60.0  
 TEMPERATURE 0.0 C  
 AMPERE RATE 6.00  
 CATALOG  
 SERIAL 11-43.11-42.11-41.11-22.06-20  
 GENERAL ELECTRIC CELLS  
 PROJECT ATS F+G

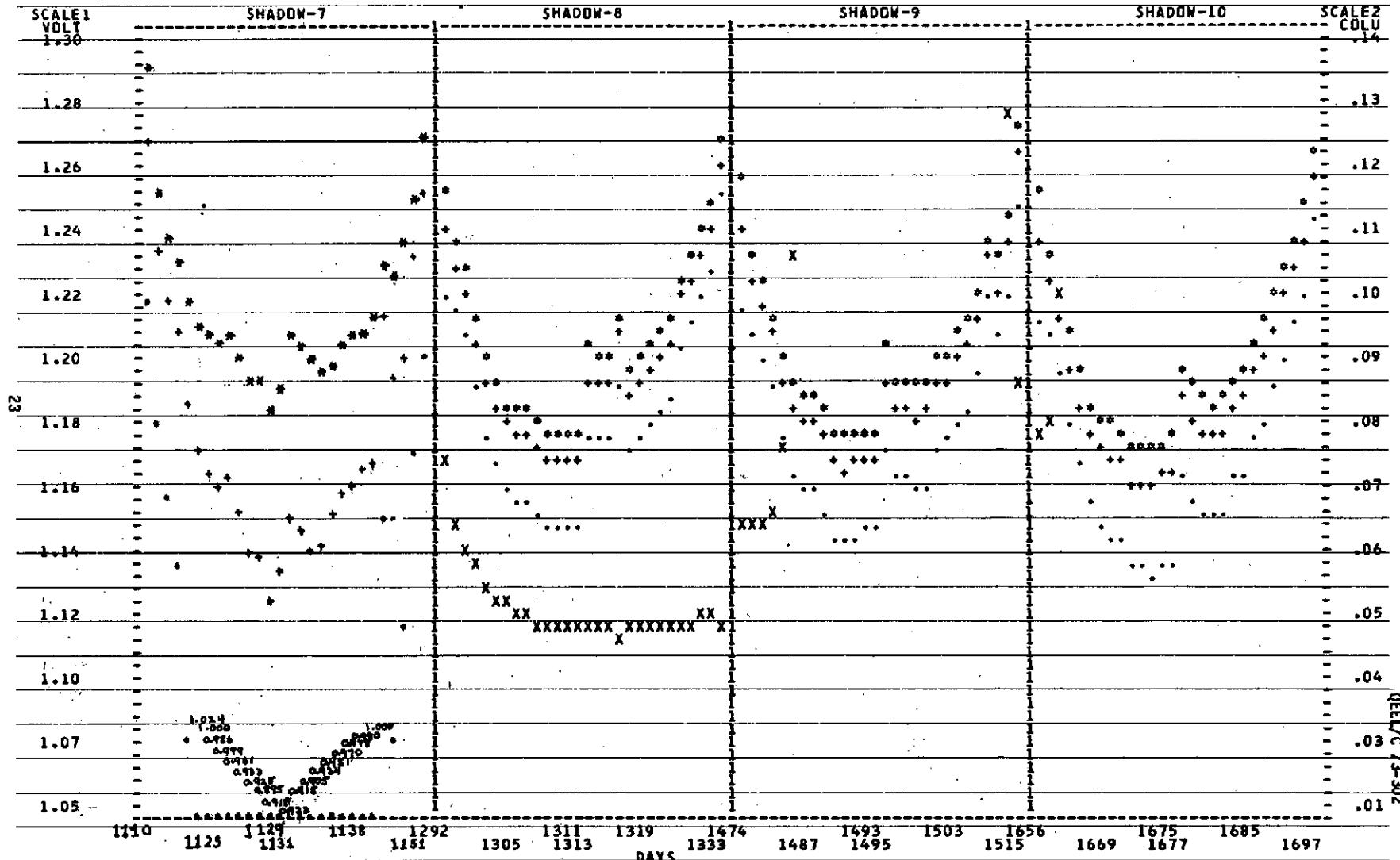


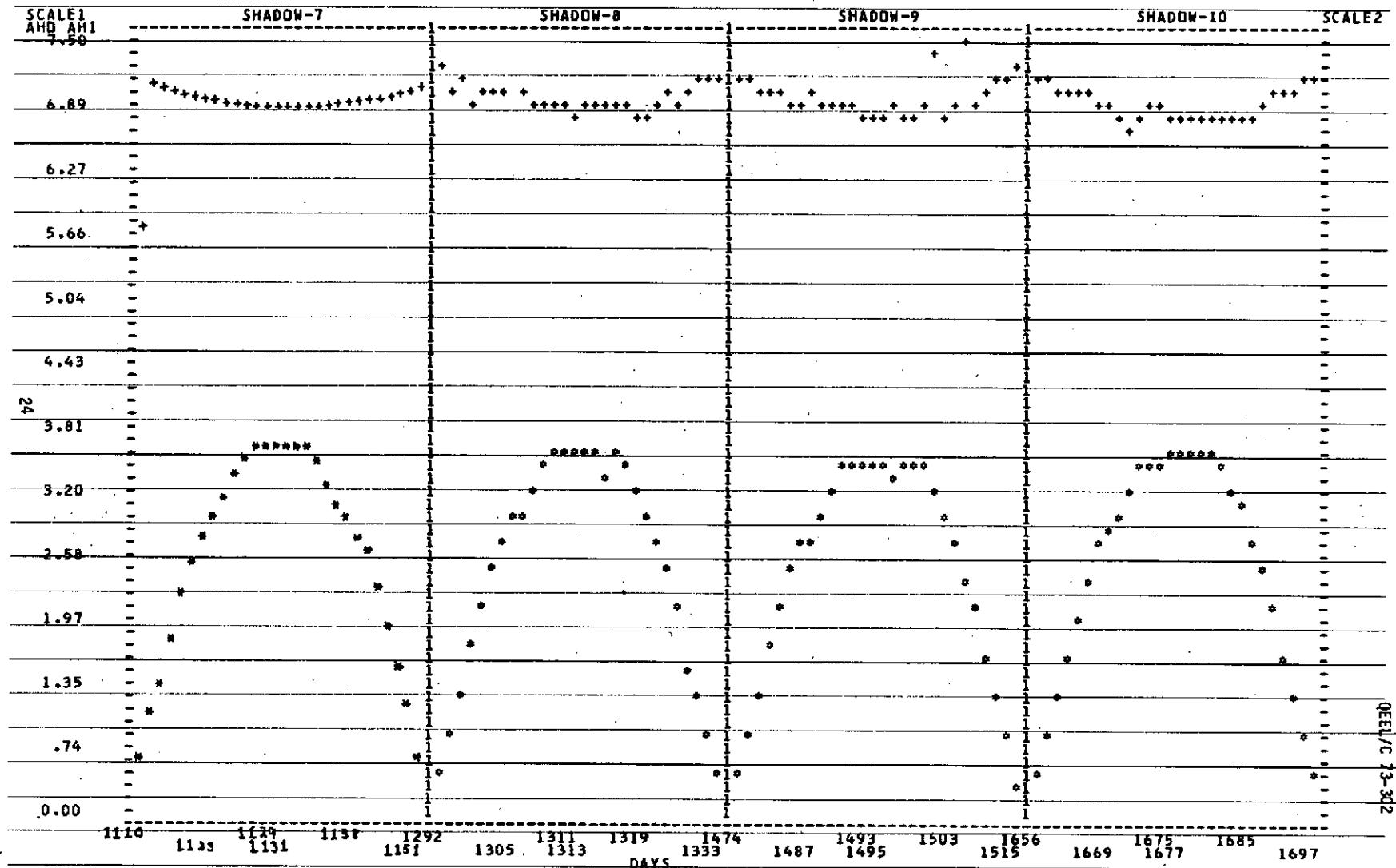
FIGURE 14

**KEY**

## SYNCHRONOUS ORBIT SHADOW PLOT

PACK 2

DEPTH DISCHARGE 60.0  
TEMPERATURE 0.0°C  
AMPERE RATE 6.00  
CATALOG  
SERIAL 11-43.11-42.11-41.11-22.06-20  
GENERAL ELECTRIC CELLS  
PROJECT ATS F+G



**FIGURE 15**

6. Sync 6: The successive eclipse seasons (7 through 10) for this pack are shown in Figures 16 to 18.

a. End-of-Charge Voltage (Figure 16): The eoc voltage of this pack has shown some erratic behavior just as previously noted for Sync 5. However, Sync 6 has remained the more stable of the two. With age, the eoc voltage of Sync 6 is erratic more than it is stable. Removal of the low cell (cell 5) on 1 February 1971 did not help the situation--if anything it aggravated it (see the voltages of eclipse 7 vs. the remaining eclipse of Figure 16).

NOTE: The coulometer voltage for eclipse 7 averaged 0.725 volt over the entire eclipse; thus it could not be plotted because it was over scale.

b. End-of-Discharge Voltage (Figure 17): During eclipse 7 the low cell voltage goes to 0.000 volts shortly prior to the capacity check. This is exemplified in the manual plotting of the data of eclipse 7. It is also exemplified in the computer print-outs except where the voltage reached 0.000 volts the cell was removed from the circuit and returned to open circuit; thus the open circuit voltage was recorded as the "low cell" voltage by the computer. The divergence between high and low cell voltages is very noticeable in eclipse 10.

NOTE: The coulometer voltage for eclipse 7 was all negative and therefore not plotted because the data was off scale. The voltages range from -0.070 to -0.170 volt throughout the eclipse.

c. Ampere-Hours In and Out (Figure 18): The plateau for the ampere-hours out decreases steadily for each eclipse.

**KEY**

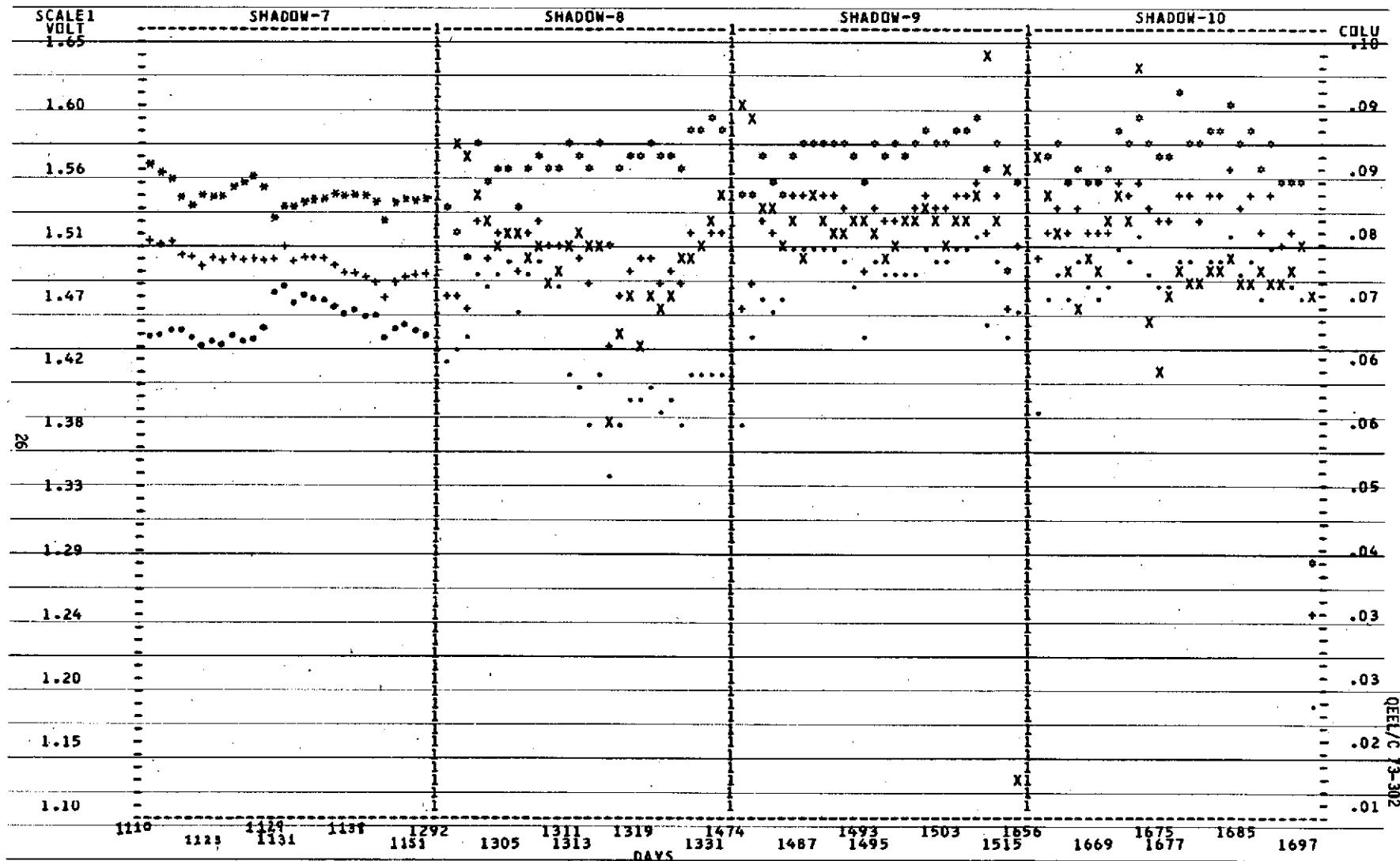
- HIGH EOC
- + AVE EOC
- LOW EOC
- X COLU EOC

SYNCHRONOUS ORBIT SHADOW PLOT

DEPTH DISCHARGE 0.0  
TEMPERATURE 0.0 C  
AMPERE RATE 6.00

AMPERE RATE 0.00  
CATALOG  
SERIAL 11-39, 11-37, 11-15, 06-09, 06, 06  
GENERAL ELECTRIC CELLS  
PROJECT ATS P+G

PACK 6



**FIGURE 16**

## KEY

\* HIGH END DISCHARGE VOLTAGE  
 + AVE END DISCHARGE VOLTAGE  
 X LOW END DISCHARGE VOLTAGE  
 X COLU END OF DISCHARGE

## SYNCHRONOUS ORBIT SHADOW PLOT

PACK # 6

DEPTH DISCHARGE 0.0

TEMPERATURE 0.0 C

AMPERE RATE 6.00

CATALOG

SERIAL 11-39, 11-37, 11-15, 06-09, 06, 06

GENERAL ELECTRIC CELLS

PROJECT ATS F+G

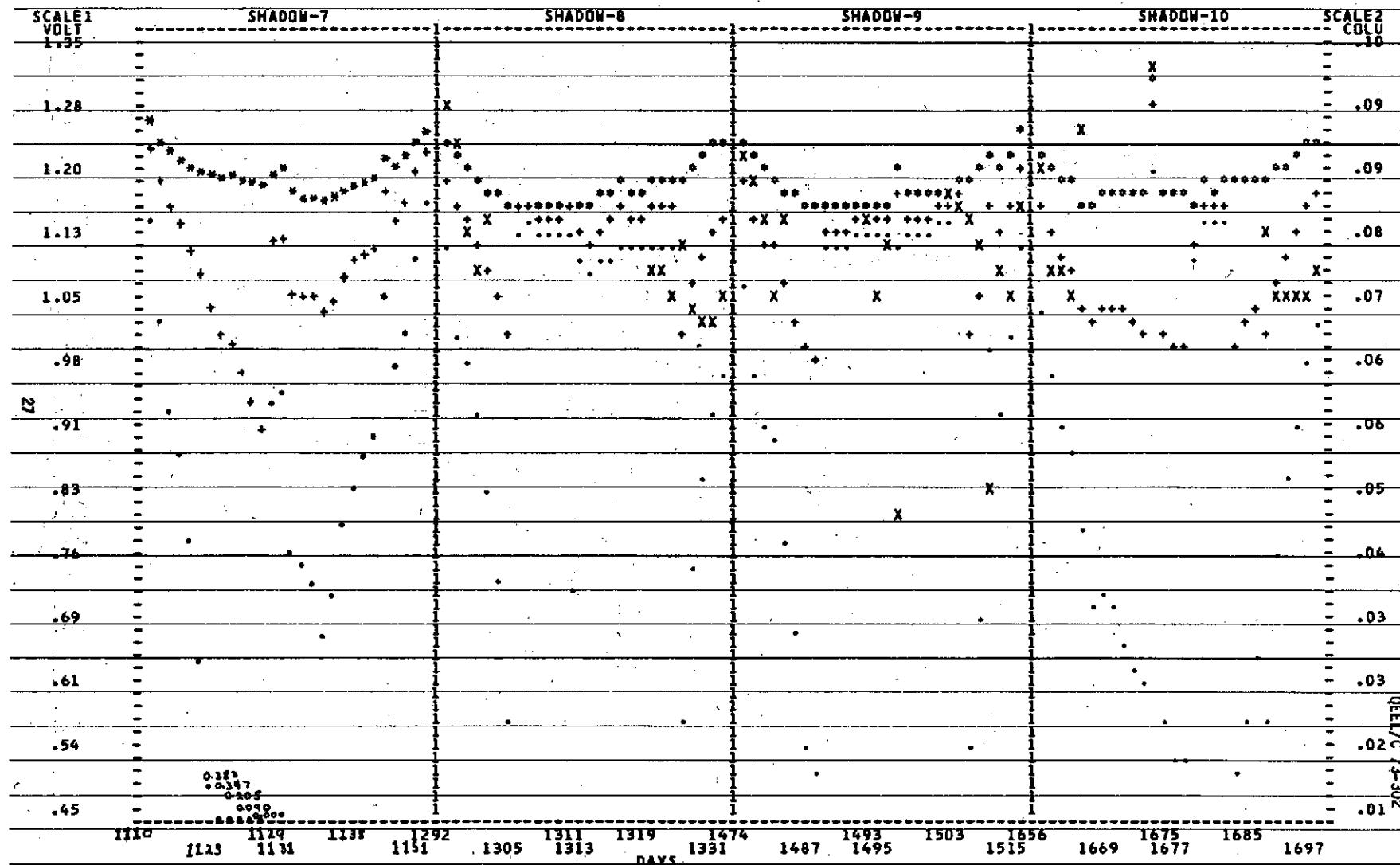


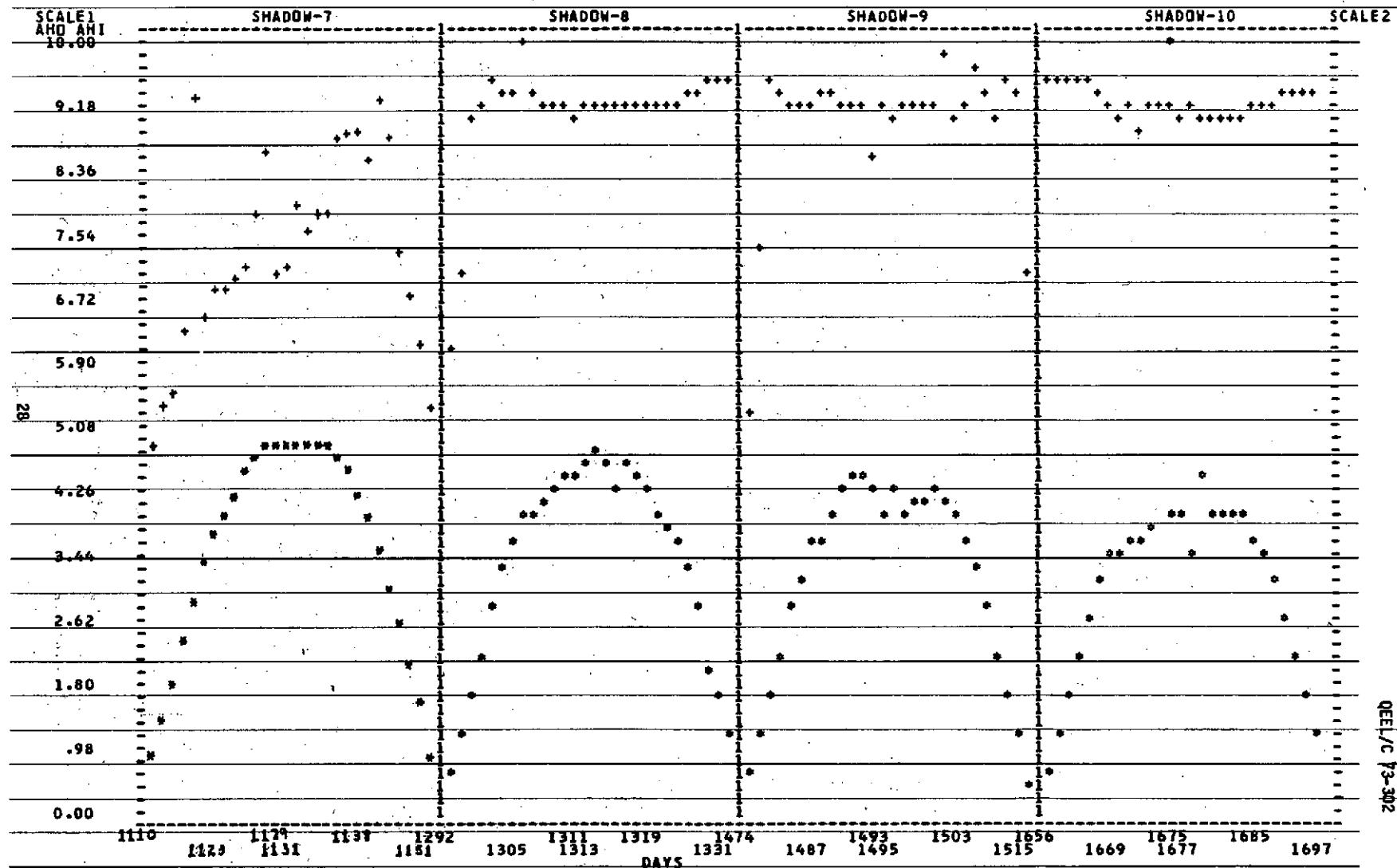
FIGURE 17

KEY  
 • AHO  
 + AHI-TOTAL

SYNCHRONOUS ORBIT SHADOW PLOT

PACK = 6

DEPTH 0.0  
 DISCHARGE 0.0  
 TEMPERATURE 0.0 C  
 AMPERE RATE 0.00  
 CATALOG  
 SERIAL 11-39, 11-37, 11-15, 06-09, 06, 06  
 GENERAL ELECTRIC CELLS  
 PROJECT ATS F+G



QEE/C 13-302

FIGURE 18

C. The test results of the sunlight (charge) seasons are shown in Figure 19. All the synchronous packs except 4B started in 1967 with a sunlight period. Hence these packs list each sunlight period as that period prior to the eclipse season in question. Pack 4B, on the other hand, started with an eclipse season, so each sunlight period for this pack is listed as that period following the eclipse season in question. As may be seen in Figure 19, all the sunlight periods for all six synchronous packs have been graphed on one sheet. This provides an excellent means of comparison. Each voltage point plotted is spaced at 5-day intervals for both cell voltage (average) and coulometer voltage--where applicable. Some of the averages extend below the range provided; the voltage ranges of these off-scale points are listed on the graph where they occur.

1. Aside from the higher voltages corresponding to the low temperature packs, there is one visible trend. Namely, the average cell voltages taper downward from the beginning of each sunlight period to the end. There are no obvious exceptions; some periods show random scatter; some show more of an average plateau; but most show the "downhill" trend from beginning to end. The last two sunlight periods of Sync 4B show very dramatic voltage drops--beginning to end.

2. The coulometer voltages (where applicable) seem to have no correlation to the cell voltages. In Sync 4B, the last two sunlight seasons show cell voltage dropping while the coulometer voltage remains essentially constant. The only exception to this is in the sixth sunlight period of Sync 4B; here the cell voltage does drop when the coulometer voltage drops. However in Sync 5, the last two sunlight periods show the coulometer voltages to be below scale, but no noticeable difference is observed in the voltage. This same observation is true for the last sunlight period of Sync 6.

3. Photographs were taken of cell 4 from Sync 6 following its removal on 22 September 1970 after completion of 1161 days on test. This removal was effected during the sunlight period prior to eclipse 8. The results are best summarized from the information accompanying each photograph of the series 1 through 8.

**CELL AND COULOMETER VOLTAGES DURING SUNLIGHT PERIODS  
(5-DAY INTERVAL)**

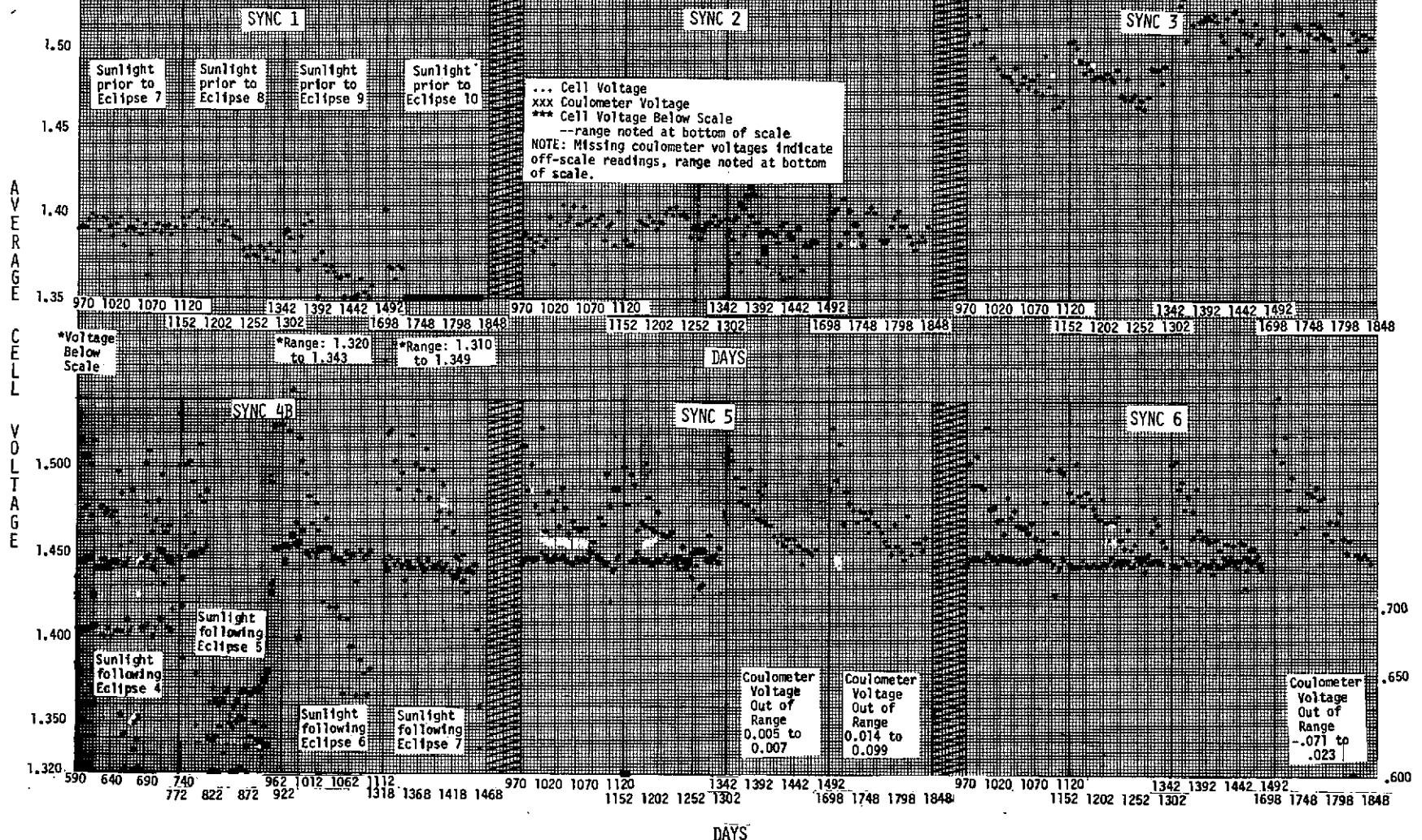
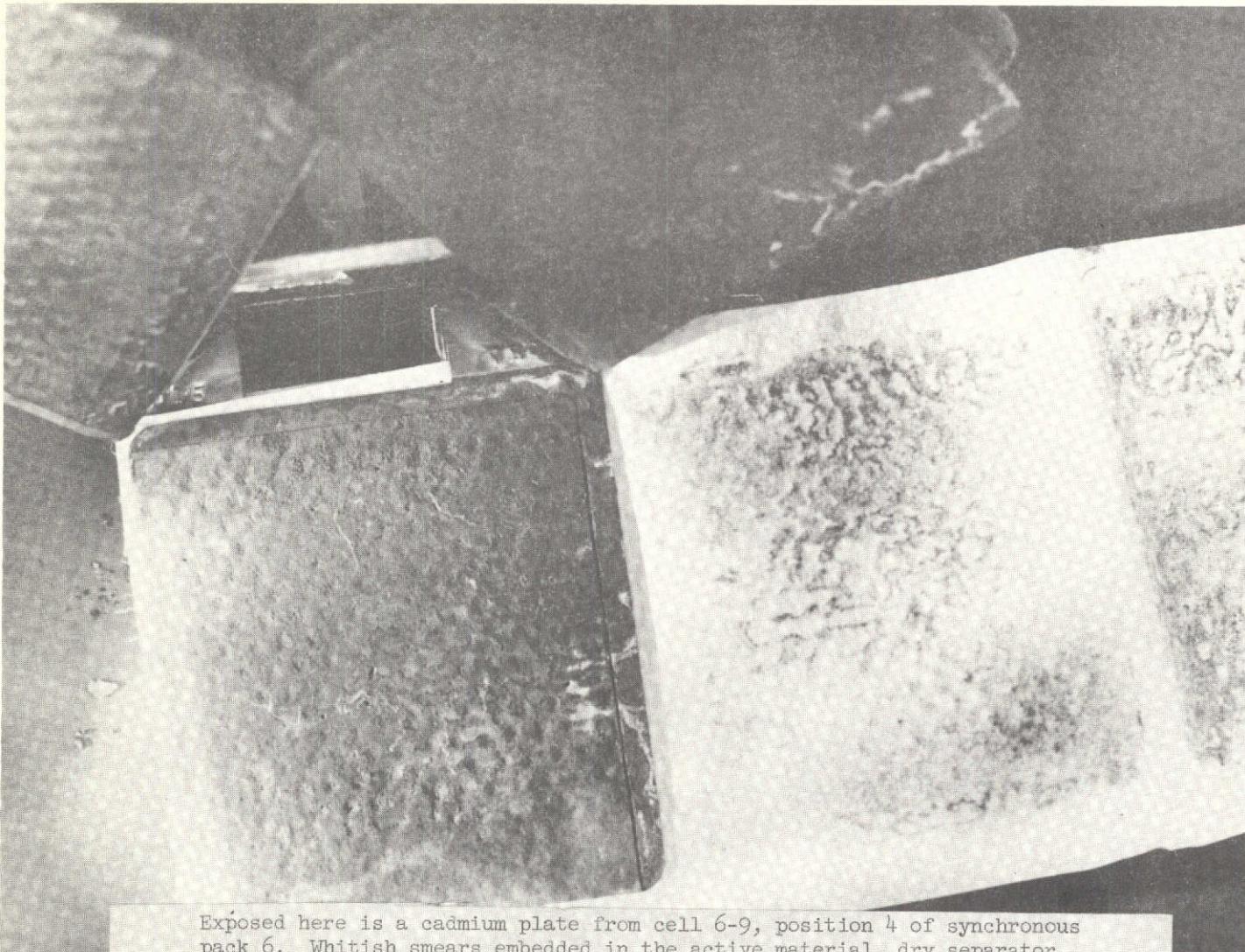


Figure 19

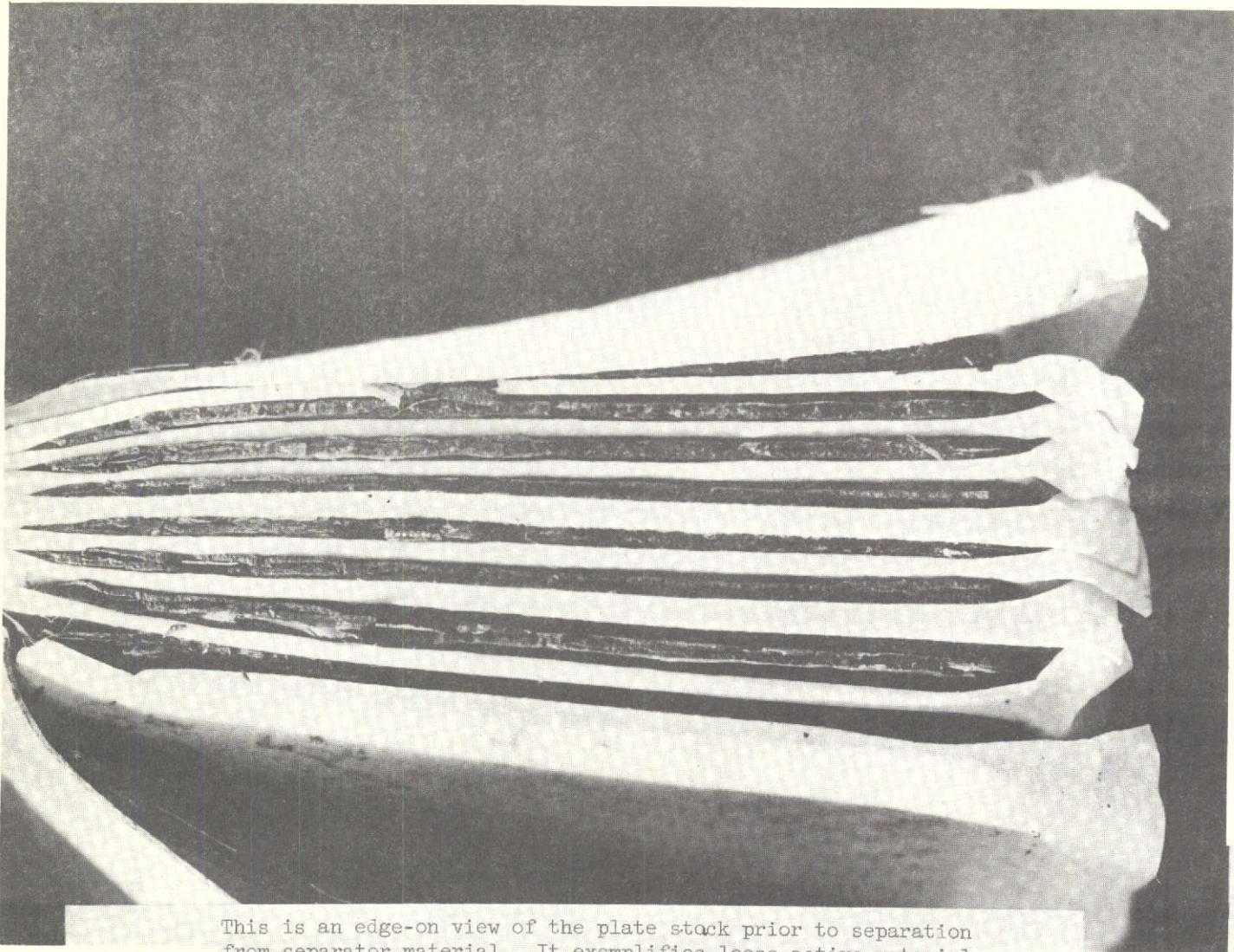
31



QEE L/C 73-302

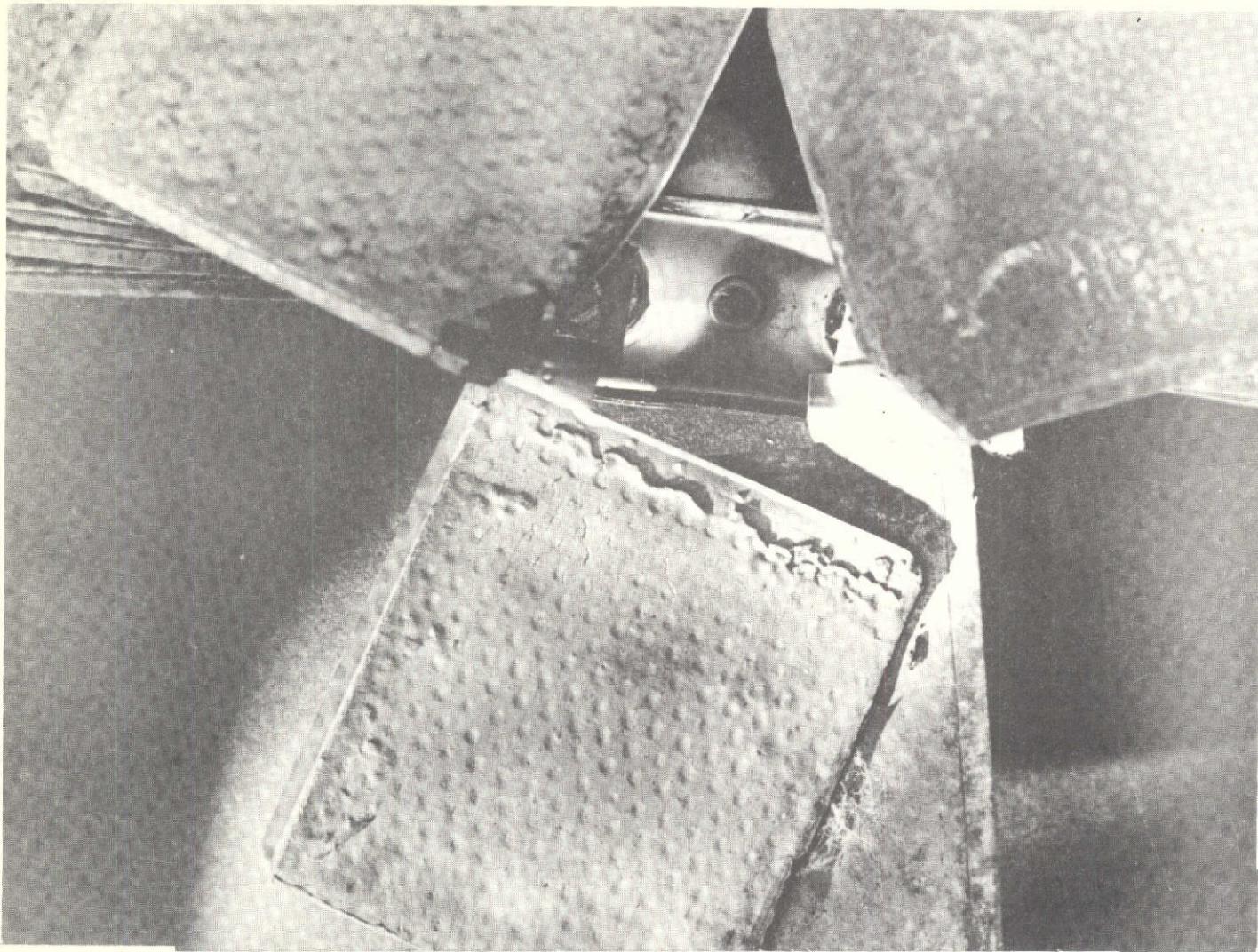
Exposed here is a cadmium plate from cell 6-9, position 4 of synchronous pack 6. Whitish smears embedded in the active material, dry separator, partial migration and partial plate oxidation (darker grey area on plate) due to exposure to atmosphere are illustrated.

Photograph 1



This is an edge-on view of the plate stack prior to separation from separator material. It exemplifies loose active material and ragged edges of the nickel plates.

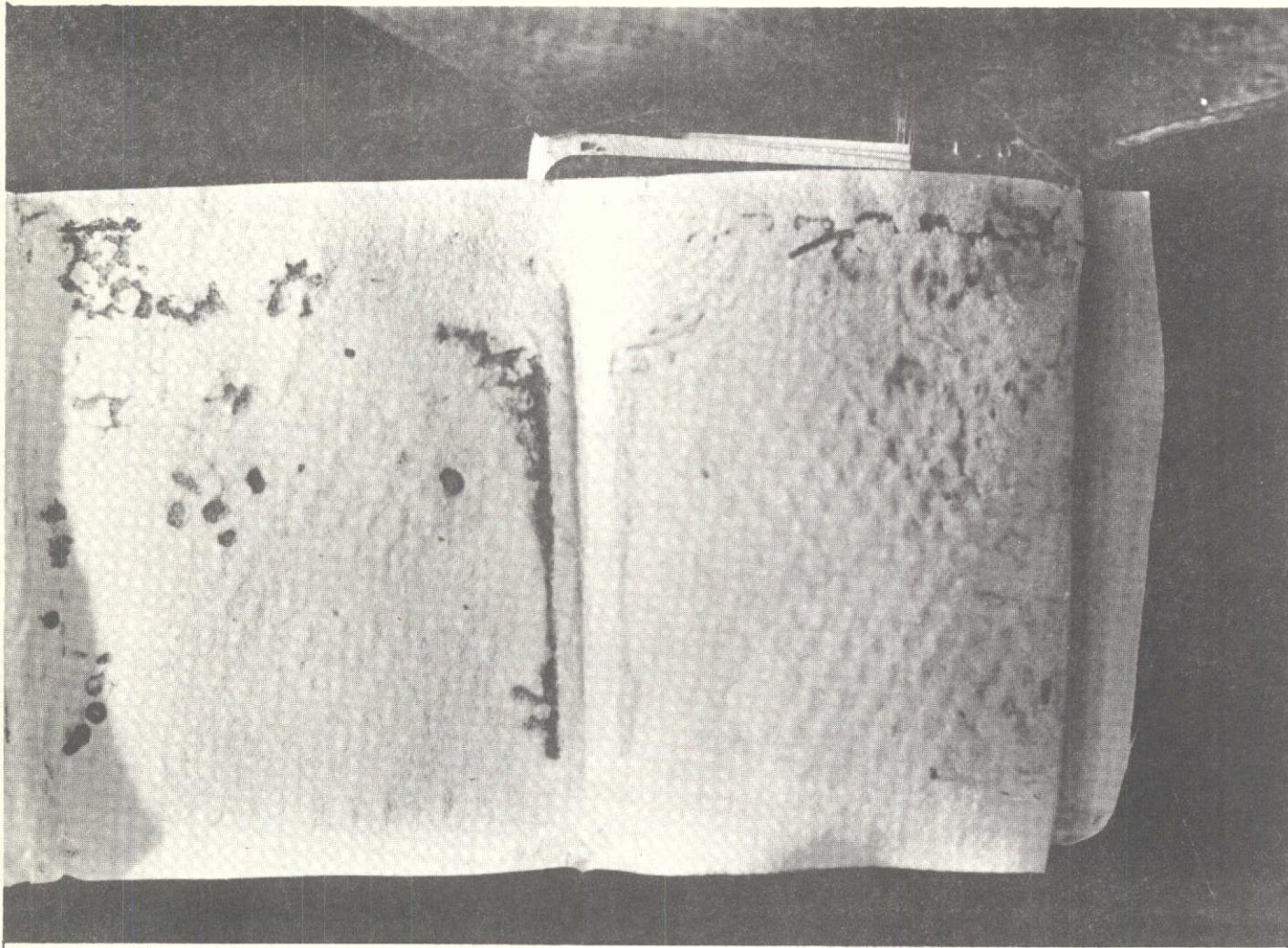
QEEL/C 73-302



This picture shows gross blistering found on the first nickel plate exposed during failure analysis.

Photograph 3

QEEL/C 73-302

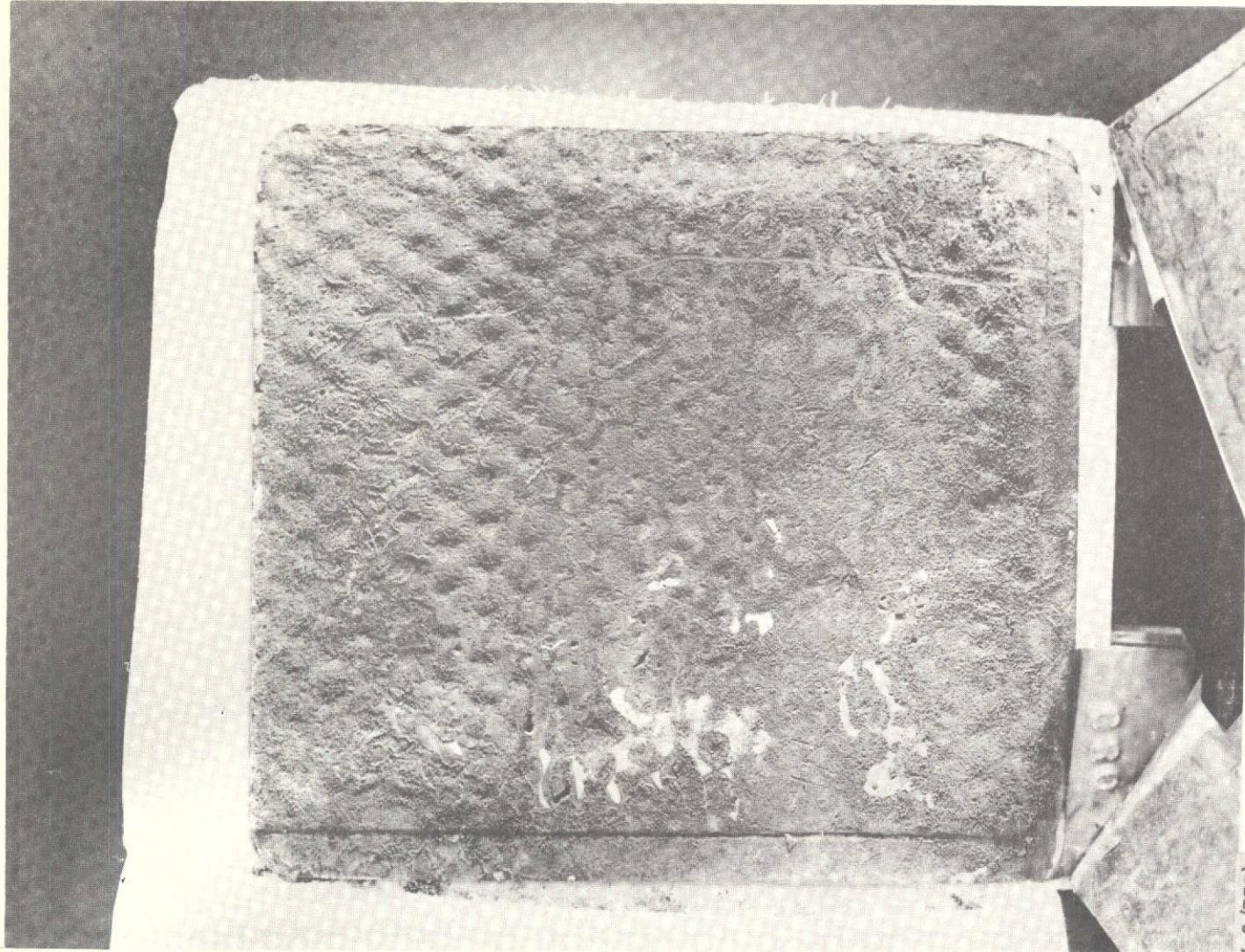


This illustrates the separator material which surrounded the nickel plate of photograph 3. Gross, localized migration is seen in the areas corresponding to the blistered areas of the plate.

Photograph 4

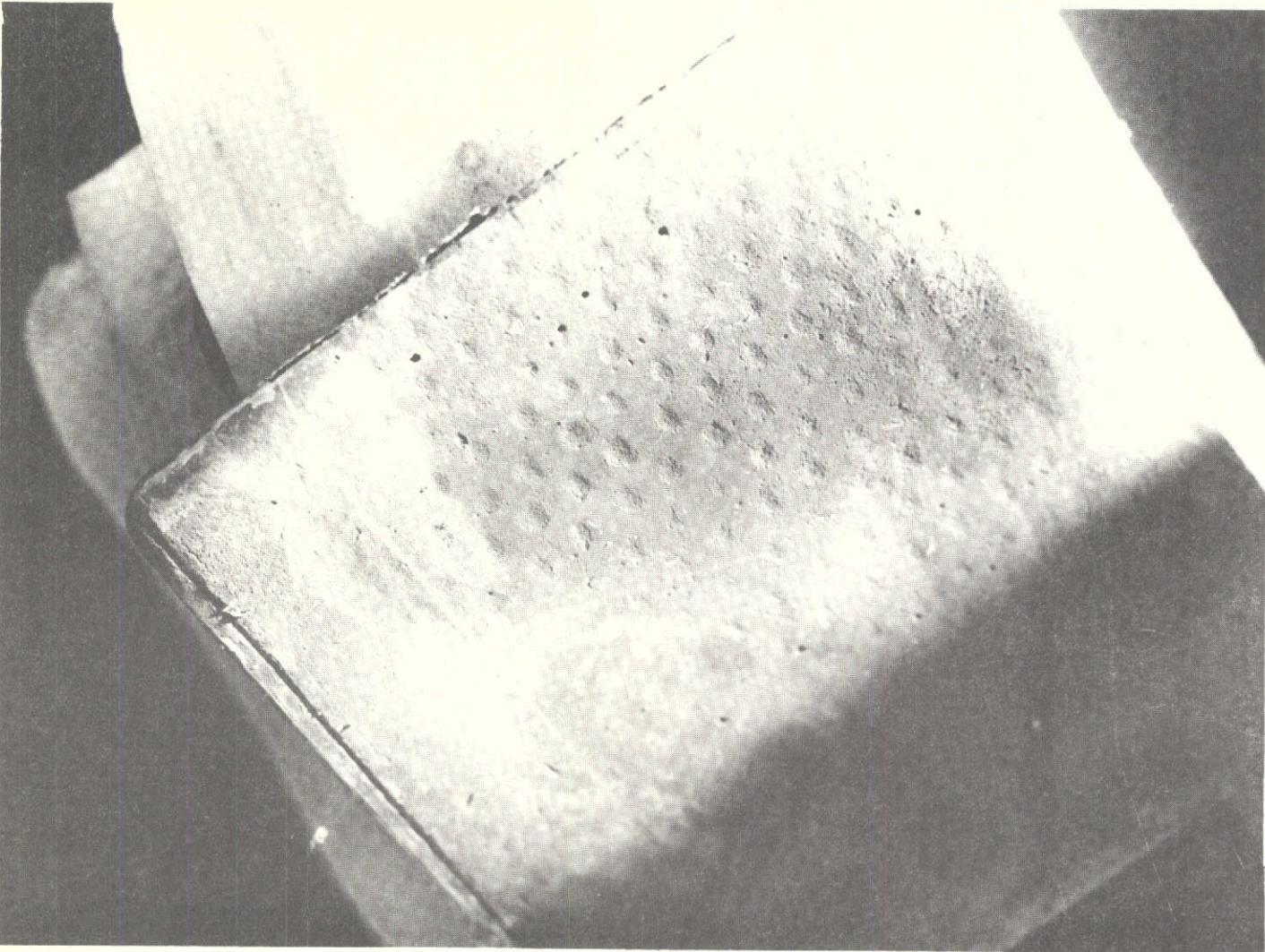
35

QEL/C 73-302



This picture further illustrates the white deposits embedded in several of the examined cadmium plates.

Photograph 5



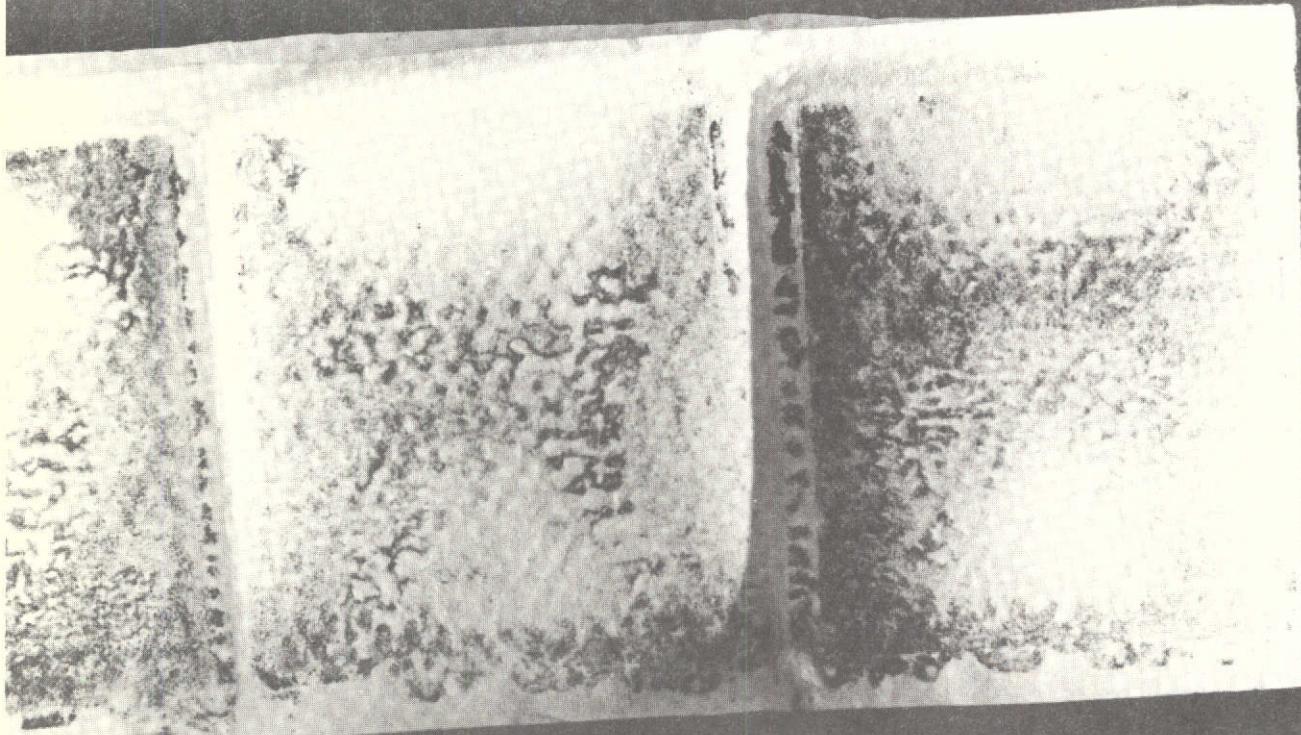
36

QEE/C 73-302

Shown here is a cadmium plate in approximately the first third of the stack. Some separator material still adheres to the plate illustrating partial deterioration.

Photograph 6

QEEL/C 73-302



37

This picture shows an "hourglass" pattern of migration on the separator material. This is caused by dryness of separator and nonuniform use of the adjacent plate's

Photograph 7

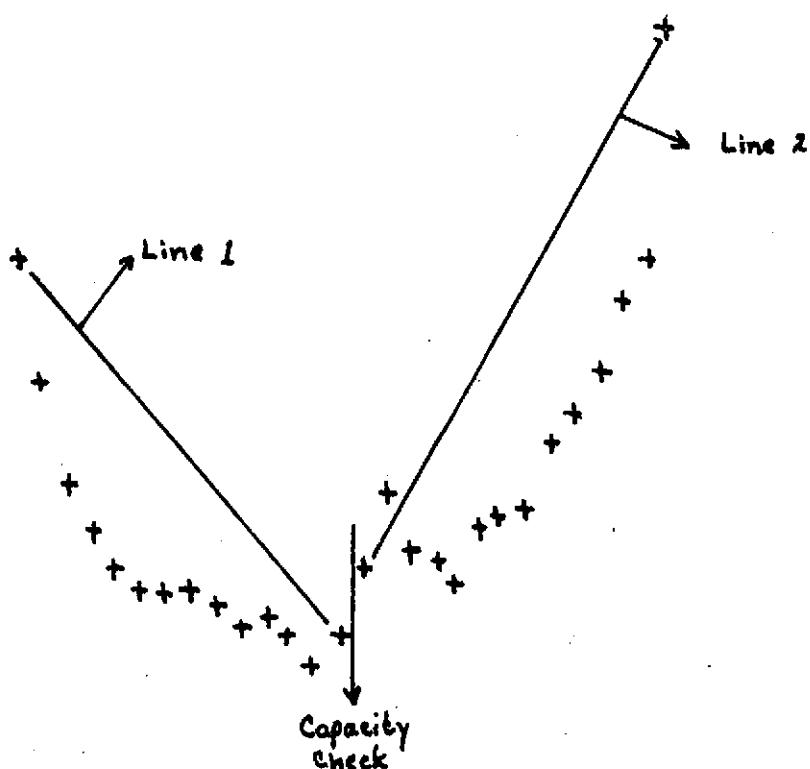


Gross blistering of the last nickel plate is illustrated. This similar to that of the first nickel plate shown in photograph 3.

Photograph 8

D. Effect of the Capacity Check on Cell Voltage:

1. Shown below is a sketch typifying the average end of discharge voltage as it varies from day to day during a given eclipse season.



In most instances, as shown, the voltage will show an increase following the capacity check and will often show a higher voltage on the last day of the eclipse than on the first day. By observation and calculation the positive slope of line 2 is greater than the negative slope of line 1. Thus with a constant discharge current but increasing cell voltage, the data indicates a slight increase in the cells' capability to deliver power during the last half of each eclipse season following a capacity check.

2. Table II lends itself to the following type of calculation:

Example: Sync 1, Eclipse 1

a. Negative Slope of Line 1

$$\frac{0.648 - 1.164 \text{ (volts)}}{1129 - 1100 \text{ (day)}} = -27.2 \times 10^{-3} \frac{\text{volts}}{\text{day}} = -27.2 \frac{\text{mv}}{\text{day}}$$

b. Positive Slope of Line 2

$$\frac{1.236 - 0.585 \text{ (volts)}}{1151 - 1131 \text{ (day)}} = 32.6 \times 10^{-3} \frac{\text{volts}}{\text{day}} = 32.6 \frac{\text{mv}}{\text{day}}$$

c. Differences of Absolute Slope Values

Line 1 - Line 2 =

$$(|-27.2| - |+32.6|) \times 10^{-3} = 5.40 \times 10^{-3} \frac{\text{volts}}{\text{day}} = -5.40 \frac{\text{mv}}{\text{day}}$$

d. Percent Difference

$$\frac{\text{Line 1} - \text{Line 2}}{\text{Line 2}} \times 100 = \frac{-5.40}{32.6} = -16.6\%$$

3. These calculations are summarized in Table III. The significant point illustrated by this table is that the majority of the values calculated for the percent difference are negative. As defined by the calculations, this means that the daily end of discharge voltage of each eclipse tends to descend less rapidly prior to the capacity check than it ascends afterward. (A positive value for the percent difference means simply the reverse.) Thus the capacity check has a slight rejuvenating effect on the cells' performance.

TABLE II

END POINT VOLTAGES AT THE END OF DISCHARGE  
DURING ECLIPSE SEASONS

Sync Pack	Eclipse Number	Day 1 (volts)	Day Preceding Capacity Check (volts)	Day Following Capacity Check (volts)	Last Day of Eclipse (volts)
1	7	1.164	0.648	0.585	1.236
	8	1.162	0.792	0.792	1.223
	9	1.145	0.816	0.816	1.223
	10	1.138	0.696	0.720	1.200
2	7	1.238	1.177	1.188	1.268
	8	1.234	1.180	1.192	1.234
	9	1.230	1.174	1.174	1.268
	10	1.224	1.168	1.162	1.270
3	7	1.260	1.184	1.194	1.286
	8	1.270	1.198	1.198	1.286
	9	1.270	1.202	1.202	1.286
	10	1.266	1.190	1.194	1.282
4B	4	1.161	1.165	1.165	1.194
	5	1.042	1.042	1.034	1.113
	6	1.140	1.130	1.150	1.210
	7	1.280	1.180	1.180	1.220
5	7	1.268	1.133	1.150	1.252
	8	1.240	1.168	1.192	1.260
	9	1.240	1.168	1.192	1.264
	10	1.236	1.164	1.188	1.256
6	7	1.225	1.120	1.052	1.220
	8	1.186	1.114	1.130	1.144
	9	1.186	1.144	1.172	1.200
	10	1.158	0.994	1.114	1.172

TABLE III

COMPARISON OF DAILY DISCHARGE VOLTAGE PRIOR TO CAPACITY CHECK  
 (LINE 1) COMPARED TO THAT FOLLOWING CAPACITY CHECK (LINE 2)  
 (SEE SKETCH OF PARAGRAPH IV.D.)

Sync Pack	Eclipse Number	Average Negative	Average Positive	Difference of Slopes [Line 1] - [Line 2] (mv/day)	Percent Difference [Line 1 - Line 2] Line 2
		Slope Line 1 (mv/day)	Slope Line 2 (mv/day)		
1	7	-27.2	+32.6	-5.40	-16.6%
	8	-19.5	+22.2	-2.70	-12.2%
	9	-17.3	+20.4	-3.10	-15.2%
	10	-23.3	+24.0	-0.70	- 2.92%
2	7	-3.21	+4.00	-0.79	-19.8%
	8	-2.84	+2.10	+0.74	+35.2%
	9	-2.95	+4.70	-1.75	-37.2%
	10	-2.95	+5.40	-2.45	-45.4%
3	7	-4.00	+4.60	-0.60	-13.0%
	8	-3.79	+4.40	-0.61	-13.9%
	9	-3.58	+4.20	-0.62	-14.8%
	10	-4.00	+4.40	-0.40	- 9.09%
4B	4	+0.211	+1.45	-1.24	- 85.5%
	5	0.000	+3.95	-3.95	-100.0%
	6	-0.526	+3.00	-2.47	- 82.3%
	7	-5.260	+2.00	+3.26	+163.0%
5	7	-7.11	+5.10	+2.01	+39.4%
	8	-3.79	+3.40	+0.39	+11.5%
	9	-3.79	+3.60	+0.19	+ 5.28%
	10	-3.79	+3.40	+0.39	+11.5%
6	7	-5.53	+8.40	-2.89	- 34.4%
	8	-3.79	+0.70	+3.09	+440.0%
	9	-2.21	+1.40	+0.81	+ 57.9%
	10	-8.63	+2.90	+5.73	+198.0%

TABLE IV  
CAPACITY CHECKS

Eclipse Season		Pack Numbers					
		1	2	3	4B	5	6
R E P O R T E D	1	1.72	7.66	6.86	5.20	6.30	5.87
	2	1.82	6.52	6.86	5.73	6.20	6.00
	QE/C 71- 183	1.82	6.22	6.56	2.67	5.95	5.73
	3	1.76	6.02	6.36	2.66	5.55	5.20
	4	2.00	5.62	6.06	7.60**	5.55	4.60
	5	2.00	5.52	5.46	2.32	3.50	3.87
	6	2.20*	5.76*	5.34*	3.17	5.34*	5.04*
	7	1.57	4.78	6.01	3.77	6.69	3.59
	8	1.40	4.20	5.70		5.60	3.40
	9	1.23	3.83	5.37		5.35	3.00

\* Cell removed following this capacity check.

\*\* High reading due to maintenance on temperature chamber.